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Impact of the Geoplasma on a Spaceborne GPS Receiver System — A Preliminary Study

J. M. Goodman

Ionospheric Effects Branch
Space Sciences Division

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It is well known that the most accurate positioning information obtainable from the GPS system, in the traditional application where the receivers are located on or very near to the surface of the earth, i.e., beneath the ionosphere is achieved through use of the two-frequency method so that the ionospheric component of the ranging error can be removed. However, in an application where a GPS receiver is itself located on a spacecraft orbiting above some of the electron content in the ionosphere and protonosphere, the question as to whether a two-frequency system is necessary may have a different answer. In this preliminary study, the parameters of the latter question are explained and the range of errors which might be experienced by a single-frequency system are estimated.

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GLOSSARY OF TERMS AND ACRONYMS

GPS	NAVSTAR Global Positioning System
BENT	Ionospheric model developed by R. Bent and used in the prediction of transionospheric effects such as group path delay.
CHING-CHIU	Ionospheric model developed by Ching and Chiu of Aerospace Corporation.
ICED	Ionospheric model developed by the US Air Force
IONOSPHERE	That region of ionization which for purpose of this report starts at 60 km and terminates in the neighborhood of 800-1000 km.
MINIMUF	Model for prediction of the maximum usable frequency for skywave paths developed by Naval Ocean Systems Center (NOSC).
PROTONOSPHERE	That region which resides above the ionosphere; it is taken herein to have its base at about 800-1000 km.
RADARC	A model for prediction of HF Over-the-Horizon Radar (OTH-R) coverage and other factors
STEC	Slant Total Electron Content; the electron content along the ray path; units are in electrons /square meter.
TEC	Total Electron Content; the number of electrons in a vertical column throughout the ionosphere having a 1.0 square meter cross section at its base.

IMPACT OF THE GEOPLASMA ON A SPACEBORNE GPS RECEIVER SYSTEM — A PRELIMINARY STUDY

1.0 Background

The U.S. Air Force is considering factors pertaining to the placement of GPS receivers on space platforms and has asked the Naval Research Laboratory (specifically Code 8300) to investigate the idea including the development of a basic design architecture. One of the factors might well be the decision to develop a suitable single-frequency receiver system which could provide the necessary and essential positioning accuracies at reduced weight and complexity. This would certainly be a desirable feature of the new receiver system architecture.

The decision to use a single-frequency format should ultimately be based upon whether or not it is concluded that the ionospheric component of ranging (or range-rate) error is unimportant in the application being considered. To achieve the best accuracies from the GPS system, it is known for the traditional application in which the GPS receivers are located beneath the ionosphere (on the surface of the earth or in close proximity within the sensible atmosphere) that a two-frequency system is essential to remove the ionospheric component of ranging error. For the new application in which the GPS receivers may generally be located above much of the electron content contained within the ionosphere or protonosphere, the question of whether to use a single-frequency or a dual-frequency system may have a different answer.

The Ionospheric Effects Branch (Code 4180) of the Space Sciences Division of NRL was tasked by the Space Applications Branch (Code 8320) of the Space Systems Technology Department of NRL to examine parameters of the problem and to estimate the range of errors which might be introduced if a single-frequency system were to be used.

2.0 Introduction

It is well-known that the ionosphere introduces an alteration in the radio-refractive index owing to the the presence of free electrons. The manifestation of this property is to introduce an excess time delay for signals which traverse the ionosphere. Fortunately, this same time delay is a frequency-dependent phenomenon; as a result it is possible to extract the ionospheric "error" term through one of several methods which take advantage of this frequency dependence.

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The GPS system uses two widely-spaced bands for ranging, so that the error in time delay introduced by the ionospheric plasma may be eliminated in an automatic fashion. Indeed, it is possible to make scientific measurements of the total electron content (TEC) through comparison of the transmission delays associated with the waveforms corresponding to the two frequencies --- suitably normalized to account for the frequency dependence. There are other sources of error in the GPS system which are not so easily removed but fortunately their magnitudes are not so potentially large. It is noteworthy that the TEC may be estimated through modelling, and this process allows single-frequency users of GPS to obtain ranging data, albeit with degraded accuracy.

It has been suggested that GPS receivers could be located on space platforms and thereby provide not only precise measurements of position through the two-frequency method but also range rate through two-frequency differential carrier phase measurements. If the measurements are sufficiently precise, then the orientation and "rotation" rates of large platforms might be derived under the presumption that the platforms are suitably laden with multiple dual-frequency GPS receivers. While this is no doubt true, factors such as weight, complexity, and cost constraints might necessitate the use of a single-frequency methodology. The question then becomes, "Can a single-frequency GPS spaceborne receiver provide for determination of platform orientation and relevant dot products with sufficient accuracy, and what are the constraints including: platform altitude, GPS constellation topology, geophysics, and so on ?"

The purpose of this report is to outline some of the factors involved in attempting to answer the question posed above, and to provide the sponsor with some preliminary guidance in connection with a single-frequency solution. The two major areas include estimates of group path delay error and measures of refractive error.

2.0 Approach

Several generalized approaches have been suggested in the context of a thorough treatment of the problem. In the long term we anticipate that rigorous ray tracing approaches may be necessary for a consideration of possible paths between the GPS space segments and the satellite platform GPS receiver(s). This treatment will no doubt require (or at least strongly suggest) that we should exploit the most current ionospheric model available. As a minimum, it is anticipated that quasi-rectilinear propagation [illegible] will be adequate but that reasonable ionospheric models will be necessitated. Indeed, it is this latter area which was a dominant factor in the involvement of NRL 4180 personnel in the first place.

In the near-term, the procedure to be followed for the purpose of providing an "order-of-magnitude" result will involve a simplification in both the propagation and ionospheric model specifications.

2.1 Group Path Delay Approach

The group-path-delay estimate will be deduced under the assumption of rectilinear propagation through a median ionospheric model which is noted for its simplicity...the so-called Ching-Chiu Model [Ching and Chiu, 1973, 1974; and Chiu, 1975]. The slant total electron content (STEC), of fundamental importance in the estimation of excess group-path-delay, is determined through integration of the Ching-Chiu profile over paths of interest. We may solve for the excess group-path-delay for arbitrary aspect angles from the GPS receiver and specified components of the GPS constellation. For the purposes of this note, we shall restrict the calculations to a limited range of paths. The spirit of the effort is to identify the postulated worst-case or at worst the "average" situation. We shall take the satellite-borne GPS receiver to be situated at two specific altitudes in this preliminary study: 100 and 1000 km. This pair of heights might constitute the basis for estimation of the upper and lower limits of ionospheric impact as far as the total electron content is concerned. Above an altitude of about 1000 km we are dealing with electron concentrations associated with a tenuous region of the upper ionosphere called the protonosphere; the densities in this region are quite small. (We are, of course, aware of the fact that the protonospheric component of TEC may be substantial as a percentage of the total during nocturnal periods.) Further, for the 100 km satellite height we will initially specify the ray orientation in the local elevation plane in increments of 5 degrees, starting with -5 and going to +10 degrees.

> [It turns out that -5 degrees corresponds to a beam depression angle for which the ray path exhibits its closest point of approach at an altitude of 60 kilometers above the earth. Of course 60 km corresponds to the base of the sensible ionosphere, being the location of the ionospheric D region. We note that for the 100 km satellite, we only transit the full ionosphere once even though a -5 degree elevation (or 5 degree depression) will correspond to one pass from 100 km to the GPS transmitter and two passes from 100 km to 60 km.]

For the 1000 km satellite, we start at -30 degrees and stop at 0 degrees, again in increments of 5 degrees.

> [For a satellite at 1000 km, we are above most of the TEC except that contained within the protonosphere. Thus if the GPS transmitters being exploited by the proposed satellite receiver are above the local horizontal, there will be a limited amount of TEC to deal with.
>
> That is the good news. On the other hand, if the situation is such that satellites must exploit GPS transmitters which present significant beam depression angles, we penetrate essentially the full ionosphere twice -- once going down and once going up. Naturally, ray obliquity effects enter in also. In effect, the greatest slant TEC and the ionospheric

group path delay error occur over the path for which the product of average electron population and the effective ionospheric path length are maximized. The irony here is that for the satellite receiver located at about 1000 km and above, we have both a worst-case and a best-case scenario possible].

[In a more detailed analysis, the strategy for computation would depend upon the anticipated variation in the TEC along adjacent ray paths in the elevation plane. For a GPS receiver at 1000 km we would specify the elevation resolution to be 5 degrees in the zenith direction, allowing this specification to apply from zenith until the local horizontal is reached; thereafter we would specify the resolution to be 1 degree and terminate the calculation at a ray depression angle such that the path between the GPS transmitter and space-borne GPS receiver just lies tangent to the earth's surface. The depression angle at which tropospheric contributions may be ignored would be flagged. For a GPS receiver located at the base of the ionosphere, the computation strategy would be different from that indicated above. The elevation resolution would be specified to be 1 degree toward the zenith direction, and this value would be used for the entire set of calculations, with the calculations being restricted in the lower half plane. For GPS receivers imbedded in the ionosphere, this latter procedure would be followed as well.]

In the azimuthal plane, we take azimuths of 0, 60, 120, 180, 240, and 300 degrees to be representative. There is no apriori estimate of a worst-case azimuth selection independent of a selection of satellite receiver coordinates.

The conditions which were selected for this preliminary study are given in Table 1.

2.2 Approaches for Estimating Refractive Error

As in the approach for determination of the TEC and the corresponding group path delay due to the ionosphere, we will use the Ching-Chiu model for refraction calculations. We shall use a wedge refraction approximation in the analysis and will deduce the cumulative refractive error along the ray trajectory by summing the incremental refraction errors introduced by successive TEC "wedges" (or gradients). For the high frequency involved in the analysis, we are justified in assessing the TEC gradients over substantial step sizes. As a first cut we take 100 kilometers as the step, and we deduce the gradient of TEC over this dimension. Further, we take the gradient of TEC to be approximated by the local derivative of TEC transverse to the ray path (and in the plane defined by the initial ray trajectory and zenith). In other words we ignore horizontal gradients in comparison to vertical gradients.

[The forgoing assumption is a convenience at this juncture but would be expected to be most plausible if ray trajectory. transits of features such as the day-night terminator, the Appleton anomaly, and the auroral zone are avoided. Even so, "elevation" errors typically dominate "azimuth" errors caused by horizontal gradients.]

Again we will use the same conditions in the refractive (elevation) error estimates as we indicated previously. (See Table 1.)

TABLE 1

PARAMETER SPECIFICATIONS

PARAMETER	VARIATION SPECIFIED
SUNSPOT NUMBER:	0, 200
DIURNAL:	0600, 1200, 1800, 0000 (LMT)
SEASONS:	Vernal & Autumnal Equinoxes Winter & Summer Solstices
ALTITUDE: (satellite)	100, 1000 km
LONGITUDE: (satellite)	90 degrees W
LATITUDE: (satellite)	80N, 60N, 40N, 20N, 0 20S, 40S, 60S, 80S
GPS POSITION:	Implicitly specified by: ray zenith and azimuth angles
RADIO FREQUENCY:	1.0 GHz

3.0 Analysis Aspects

3.1 Ionospheric Model

The Ching-Chiu model has been used for a number of applications in which speed of operation is paramount and elegance requirements (not to be confused with accuracy) may be suppressed. Appendix A contains a listing of the model. Code 4180 has exploited the model for determination of HF maximum usable frequencies (MUF's) corroborate the output from special purpose with

microcomputer models such as MINIMUF. Code 4180 has compared these results with main-frame HF system performance models such as IONCAP with generally good results except in the neighborhood of the day-night terminator. In view of our experience with the Ching-Chiu model we have used it for near-term investigation in the current context. Follow-up treatment may involve integration of the ionospheric sub-model contained in RADARC or ICED. RADARC is a model which has been developed explicitly for use in the solution of OTH radar problems; and ICED is an Air Force model which has just recently been developed and features a considerable potential with respect to update capability and in terms of its efficacy at high latitudes (where other models are not adequate).

Figure 1 is a graph of the Ching-Chiu profile showing the contributing E, F1 and F2 layers.

It is well-known that the TEC is the prime indicator of group path delay for earth-space paths and Klobuchar of AFGL has developed a number of region-specific models. The "community" of those who make it a business to study TEC and led by Klobuchar, has also exploited the so-called BENT model to achieve a global representation of TEC as well as group-path-delay directly. For space-to-space paths (and especially those that are at negative elevation angles) the direct use of these models is not possible. However, for low orbitors and non-negative elevation angles we could nonetheless make comparisons for completeness. This is not done in the present report.

We make note in passing of the single-frequency user ionospheric time delay Algorithm developed by Klobuchar [1975]. It is designed to correct for approximately 50 % of the delay error for GPS users ... this error being largely ionospheric in nature. This algorithm has its best success at middle latitudes but performs rather poorly in the near-equatorial zone owing to the simplicity of coefficient representation in the model [Klobuchar, 1981]. Insufficient data has been obtained in the arctic environment to determine its exact performance in auroral and polar cap regions. The Klobuchar algorithm in its operational form consists of four coefficients to represent the worldwide behavior of the "average" TEC. The actual behavior is much more complex than this ... especially over the equatorial and high latitude zones. The model is not intended to correct for short-term variability in the TEC, and in fact noble attempts to adapt the coefficients or update the solar activity values which "drive" the model have not met with much success.

Klobuchar et al [1987] have obtained TEC data for the first time at a polar cap site located at Thule, Greenland using dual frequency transmissions from orbiting satellites rather than geosynchronous areas. These workers, who did their study in 1984, found extremely large variability in TEC. Quasi-periodic trains of enhancement of the order of 10^{17} electrons/m^2 over periods as short as ten minutes were observed. It was found that the absolute values of TEC in the dark polar cap, occasionally exceeded the diurnal midlatitude maximum values. There is no TEC model currently available to handle this behavior.

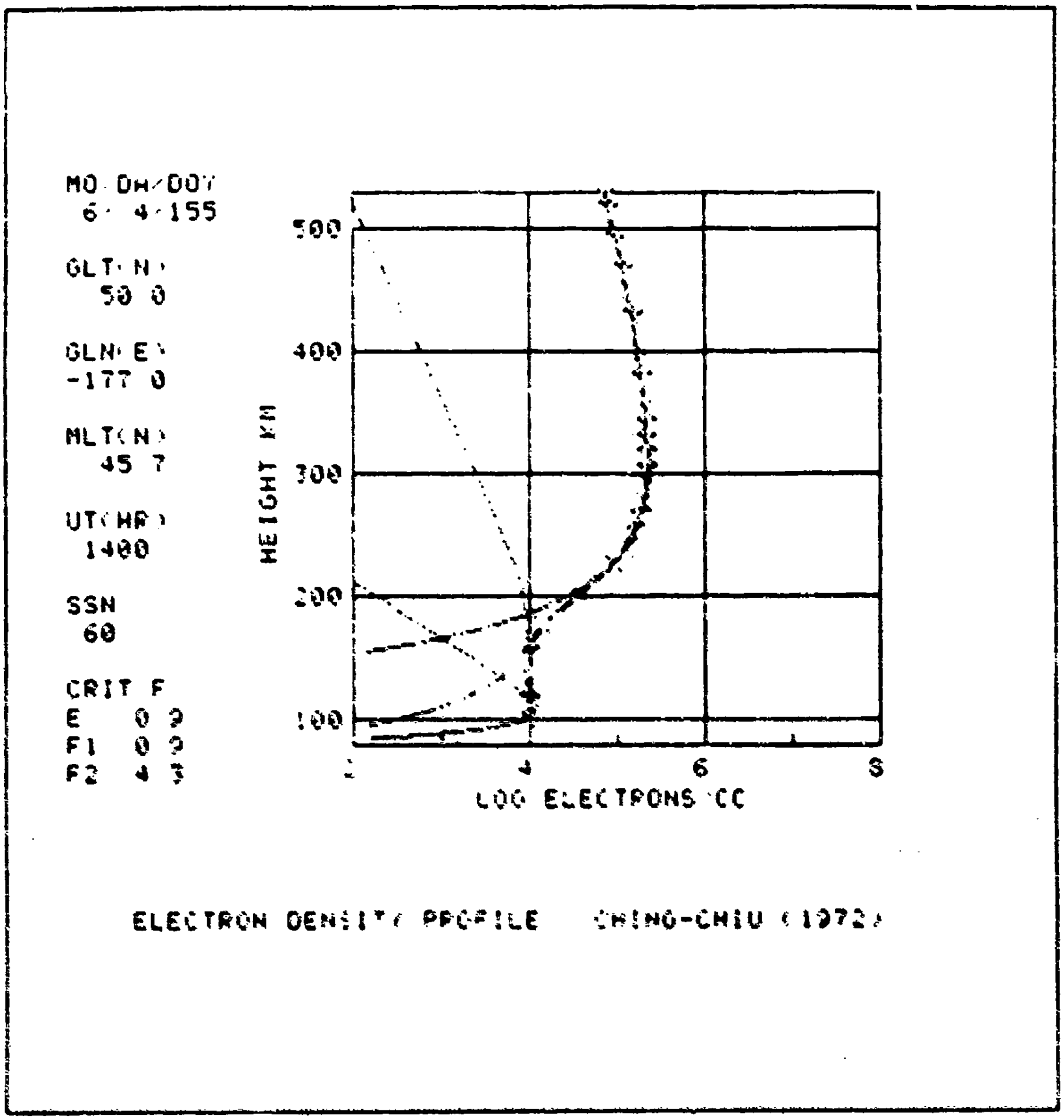
MO/DA/DOY
6/4/155
GLT(N)
50.0
GLN(E)
-177.0
MLT(N)
45.7
UT(HR)
1400
SSN
60
CRIT F
E 0 9
F1 0 9
F2 4 3
HEIGHT KM
500
400
300
200
100
2
4
6
8
LOG ELECTRONS/CC
ELECTRON DENSITY PROFILE CHING-CHIU (1972)

FIGURE 1

3.2 Geometry of the Problem

Estimates of group-path-delay for paths above the local horizontal are limited on the upper side by results obtained in traditional earth-space configurations, with the contribution between ground level and E layer height (90km) being virtually zero.

This means that the excess group path delay exhibits only a small tropospheric contribution between 0 and 90 km, after which the delay will begin to grow with altitude.

Naturally, for near-zenith propagation, the space-to-space excess group path delay due to the ionosphere, will decrease monotonically with height. This decrease will be modulated by structure which is encounter's over the path between the receiver platform and the GPS transmitter.

For negative elevation paths, we find that there are two opportunities for the ionosphere to be penetrated on the same trajectory. An interesting case corresponds to a path linking a platform located just above the sensible ionosphere (say at an altitude of 1000 km or so) to a GPS transmitter located just above the limb of the earth. In this case, the excess group-path-delay due to the ionosphere (and the troposphere for that matter) will be on the order of twice that expected for a conventional low elevation earth-space path.

3.3 Sample "Back-of-the-Envelope" Calculations

3.3.1 Group-Path-Delay

Given the remarks in the previous section, it is possible for one to get a first-order upper bound on the single-frequency excess group-path-delay with the following assumptions:

a. Take the path to be such that the ionosphere is penetrated twice. (The TEC to be used will be twice the maximum observed value for a single path).

b. Take the so-called "obliquity factor" to be maximized. (The ratio of STEC to TEC is taken equal to about 5 as an absolute maximum -- admittedly a high value. For a typical earth-space path, the ratio is on the order of 3 or so.)

c. Take the TEC value to be commensurate with the largest which has generally been observed. This would normally occur in the vicinity of the equatorial or Appleton anomaly, and would be on the order of 100 "TEC units" [Goodman and Martin, 1988], where the standard definition of a "TEC unit" is used:

$$1 \text{ TEC Unit} = 10^{16} \text{ electrons/m}^2$$

Furthermore this largest amount might arguably be anticipated to occur in the mid-afternoon period at solar maximum and at an epoch away from the summer solstice ... perhaps near equinox.

d. Use the following expression to deduce the excess group path delay error caused by the ionosphere (in nanosec):

$$T[nS] = 1.345 \text{ STEC } f^{-2}[GHz] \quad (1)$$

where S is the obliquity or secant factor,
STEC is the slant TEC along the ray path, measured in "TEC units",
and T[nS] and f[GHz] are measured in nano seconds and GigaHertz respectively.

(Note that STEC stands for the slant TEC. It is also true that STEC = TEC x "the obliquity factor, which is termed S". Thus we have STEC = S(TEC) or STEC for short. The values of STEC and TEC are usually given in so-called "TEC units", defined above.)

According to (1) above, the ionospheric delay at 1 GHz is 1.345 nS for every "TEC unit" encountered along the ray path. Taking the above assumptions (i.e.,a-d) into account, we have T = 1340 nS for an upper bound at 1 GHz for a postulated worst case scenario. Typical ionospheric errors would be much less than this ... perhaps in the range between a few nS and several hundred nS depending upon the satellite orbit, ray path geometry, ionospheric condition, and so on. Only under unusual circumstances would one expect the error to be much more than the estimated upper bound of about 1340 nS. A two-frequency system could naturally remove this ionospheric error. (However, even a two-frequency system would have to deal with twice the normally-encountered tropospheric delay.)

3.3.2 Refractive (Elevation) Error

It is well known that transverse gradients in electron content can produce radiowave bending given by the following formula [Goodman. 1976]:

$$E(s) = Kf^{-2} \frac{d}{dx}\int [N(s)ds] \quad (2)$$

where s is measured along the ray trajectory,
x is transverse to the ray path,
f is the radiofrequency (Hz)
K = 40.5 with MKS units being employed.
E is expressed in radians
N is in electrons/cubic meter

Taking the integral $\int N(s)\, ds$ = STEC(s), we have the expression:

$$E[mR](s) = 0.405 f^{-2} [GHz]\ d/dx\ STEC(s) \quad (3)$$

where x is in units of kilometers,
STEC is in TEC units,
E[mR] and f[GHz] are expressed in milliradians
and GigaHertz units respectively.

Taking the TEC transverse gradient to be 1 TEC unit per km, we can obtain an order of magnitude estimate for the angular refraction E. This specified gradient is likely a reasonable guess for an upper limit. Taking it, the wedge refraction becomes roughly 0.4 milliradian at 1 GHz. Thus we look for numbers of this order or less.

3.4 Calculations

As indicated in section 3.1, a listing of the Ching-Chiu model is provided in Appendix A. Codes have also been developed for exploiting this model in connection with the parameters outlined in section 3.3. These codes are also provided in Appendix A. They include by name:

1. Program GPSTST
2. Subroutine CHNCHU
3. Subroutine BEGIN
4. Subroutine MAGFLD
5. Subroutine MON1
6. Program GPS-FAST
7. Subroutine DATAIN
8. Subroutine START
9. Subroutine MFIELD
10. Subroutine ELDENS

These programs and subroutines have been written in FORTRAN 77 by C. Myers.

Appendix B contains a compilation of selected computer runs which show the group path delay which would be introduced for the conditions indicated in Table 1. The TEC values which correspond to the delays are also provided. A perusal of the data sets would appear to bear out the assertion made in the previous section that 1340 nS is a worst case situation. It is noteworthy that the canonical frequency for calculation purposes is 1.0 GHz. Transformation to a specific GPS frequency may be obtained by multiplication of the result by

$$f^{-2}[GHz]$$

to obtain the proper result. The so-called L1 and L2 carrier frequencies on GPS are 1.575 and 1.227 GHz respectively. Thus, for the GPS case we would multiply the group-path-delay results in the tables by 0.403 and 0.664 respectively. Clearly the tabular results are pessimistic (i.e., higher values).

Appendix C contains a compilation of output from computer runs which are consistent with those selected in Appendix B. The program GPS-FAST (termed FASTTRACE in the Appendix captions) yields the DELAY (mS), the refraction ANGLE

(mR), and the transverse DISTANCE (meters) as a function of azimuth (clockwise from North) and ELEVation angle (positive upward). Again we take the canonical frequency to be 1.0 GHz.

The ANGLE and DISTANCE results are quite naturally dependent upon the distance of traversal along the ray path. Only the ultimate values following ray exit from the ionosphere are presented in Appendix C. Clearly there is variability of each parameter. In Table 2 is an example calculation showing how DELAY, ANGLE, and (transverse) DISTANCE vary with RANGE along the path. Notice that the ultimate "exited" value is smaller than the maximum value which is seen to occur (in this example) at a range of 4,400 km.

4.0 Discussion

4.1 Group-Path-Delay

It is demonstrated by the data sets associated with the climatological Ching-Chiu Model of TEC that significant group path delay errors may be introduced if the satellite-borne GPS single-frequency receivers are located near the base of the ionosphere (i.e., 100 km). This would be expected owing to the fact that all of the TEC will be penetrated, similar to an earth-space path. It is also shown that ray zenith angle plays a key role inasmuch as it determines the amount of slant electron content or STEC that is involved. For a satellite near the base of the ionosphere, the STEC is more or less a monitonically increasing function of ray zenith angle although there is a moderate decrease in STEC for ray depression below the horizontal. The initial value of TEC (at a zenith angle of 0 degrees, or an elevation of 90 degrees), is generally the smallest value that may be encountered, everything else being taken equal.

For a satellite located near the top of the sensible ionosphere (i.e., 1000 km), the STEC is a monotonically increasing function of ray zenith angle over much of the full range of possible values. However the STEC is relatively slight near zenith and remains nearly so as the zenith angle is increased to 90 degrees. Marked increases in TEC are observed as the ray paths dip below the horizontal. Ray depression angles down to about 30 degrees or so (i.e., zenith angle of 120 degrees) are possible without intersecting the spherical surface corresponding to the troposphere (at 60 km over the surface of the earth). For depression angles corresponding to paths which just barely touch the F2 peak twice (once going down and once going up), the STEC is approximately maximized. For paths corresponding to the maximum allowable depression angle (highest zenith angle also), the STEC will begin to moderate. This may seem surprising since the lower ionospheric TEC comes into play in this case as well as the topside TEC. The reason for this purely geometrical anomaly is because the effective obliquity factor "S" in STEC overcompensates for the decrease in the TEC itself.

In short we find that low orbitors will experience a relatively moderate variation in STEC over the full range of ray zenith angles ... almost like earth-space propagation. For the case where the satellite is near the top of the

TABLE 2

SATELLITE: 40.N 90.W 1000 KM ALT
DATE-TIME: 07/01/87 1200 HOURS
HEADING : 180 DEGREES
SUN SPOT NUMBER: 200

RANGE	KILOMETERS
DELAY	NANOSECONDS
ANGLES	MILLIRADIANS
DISTANCE	METERS

RANGE	DELAY	ANGLE	DISTANCE
100.	0.00	0.000	0.000
200.	0.00	0.000	0.000
300.	0.00	0.000	0.000
400.	0.00	0.000	0.000
500.	0.00	0.000	0.000
600.	0.00	0.000	0.000
700.	0.01	0.000	0.000
800.	0.01	0.000	0.001
900.	0.03	0.000	0.001
1000.	0.05	0.000	0.002
1100.	0.10	0.000	0.005
1200.	0.20	0.001	0.009
1300.	0.37	0.002	0.017
1400.	0.70	0.003	0.032
1500.	1.26	0.006	0.057
1600.	2.20	0.009	0.095
1700.	3.69	0.015	0.148
1800.	5.90	0.022	0.216
1900.	8.97	0.029	0.285
2000.	12.94	0.034	0.336
2100.	17.65	0.034	0.338
2200.	22.83	0.026	0.256
2300.	27.94	0.006	0.064
2400.	32.56	-0.023	-0.231
2500.	36.33	-0.058	-0.585
2600.	39.21	-0.094	-0.935
2700.	41.34	-0.123	-1.233
2800.	42.95	-0.146	-1.460
2900.	44.25	-0.162	-1.624
3000.	45.39	-0.174	-1.744
3100.	46.45	-0.184	-1.839
3200.	47.49	-0.193	-1.929
3300.	48.55	-0.203	-2.033
3400.	49.70	-0.217	-2.174
3500.	51.08	-0.239	-2.390
3600.	52.94	-0.273	-2.727
3700.	55.79	-0.324	-3.244
3800.	60.41	-0.398	-3.978
3900.	67.86	-0.490	-4.900
4000.	79.15	-0.589	-5.892
4100.	94.78	-0.677	-6.770
4200.	114.38	-0.737	-7.367
4300.	136.69	-0.761	-7.608
4400.	159.96	-0.753	-7.525
4500.	182.44	-0.719	-7.195
4600.	202.61	-0.672	-6.720
4700.	219.54	-0.621	-6.207
4800.	232.92	-0.574	-5.745
4900.	242.93	-0.535	-5.345
5000.	250.07	-0.505	-5.049
5100.	254.97	-0.484	-4.838
5200.	258.20	-0.470	-4.695
5300.	260.26	-0.460	-4.603
5400.	261.54	-0.455	-4.545
5500.	262.31	-0.451	-4.510
5600.	262.76	-0.449	-4.490
5700.	263.02	-0.448	-4.478
5800.	263.16	-0.447	-4.472
5900.	263.24	-0.447	-4.468
6000.	263.28	-0.447	-4.466
6100.	263.30	-0.447	-4.465
6200.	263.31	-0.446	-4.465
6300.	263.32	-0.446	-4.464
6400.	263.32	-0.446	-4.464
6500.	263.32	-0.446	-4.464
6600.	263.32	-0.446	-4.464
6700.	263.32	-0.446	-4.464
6800.	263.32	-0.446	-4.464
6900.	263.32	-0.446	-4.464
7000.	263.32	-0.446	-4.464

NOTE: This table gives the ionospheric group-path-delay as a function of range for a frequency of 1.5 GHz and beam depression angle of 25° (i.e., elevation angle of -25°). The distance is the departure perpendicular to the nominal rectilinear path.

ionosphere, we find a sharp variation in STEC with probably 90% or more encountered between zenith angles of 90 degrees and 120 degrees.

For satellites which are located at 1000 km or above and which can access GPS at elevations above the horizontal, the STEC is that which is encountered between the 1000 km surface and the height of the GPS. This is roughly the protonospheric value times the obliquity factor. A rough measure of the protonospheric value may be taken to be up to about 40% of the TEC during periods of time when the "ionospheric" TEC (from 100 to 1000 km) is smallest.

(Note: We have heretofore spoken of the STEC as the number of electrons between the satellite and the GPS transmitter, and the TEC as the equivalent amount in an effective vertical slice corresponding to the same path. In fact we may break up the TEC into two terms conveniently: one term is that which corresponds to the region below 1000 km which is legitimately the "ionospheric" TEC, and the second term which corresponds to the region above 1000 km and is legitimately the "protonospheric" TEC. Since most of the TEC (and STEC for that matter) is located below 1000 km (especially during the daytime), we sometimes refer to the TEC as simply the ionospheric TEC even though the following relation is true in general:

$$TEC = ITEC + PTEC$$

where ITEC = Ionospheric TEC and,
PTEC = Protonospheric TEC

We shall tacitly assume that the protonospheric content is roughly a constant function of local time. Klobuchar, Soicher, and others have shown that the protonospheric content is 20 to 40 % of the ionospheric content during nocturnal hours. We shall take 40% of the so-called DC term in the Klobuchar time-delay model as a crude estimate of the protonospheric value for these purposes. The DC term is simply the smallest irreducable amount of group path delay which is observed for a zenithal path.)

This smallest value is essentially the DC term in the Klobuchar time delay model which we would now multiply by the factor 0.40 (noting that the Klobuchar model results are reckoned in nanosecond units rather than TEC). An estimate of the DC term at 1.6 GHz in Klobuchar's model is found to range between 5 and 15 nS for high solar activity conditions with the largest values occurring in the equatorial zone. For purposes here, we may regard the increase in delay (and STEC) due to the obliquity factor as compensated for by the decrease in delay due to the 40% factor. Thus we are talking about excess TEC-related group path delay errors of about 15 nS at worst for a frequency of 1.6 GHz if the satellite

is orbiting at an altitude of 1000 km and accessing assets of the GPS constellation which are above the local horizontal. For low solar activity, and for satellite paths away from the equatorial zone, we will encounter only a few nS for the same conditions.

For satellites orbiting in the range between 100 and 1000 km, the situation will range between that observed at the two extremes.

4.2 Refractive Error

As far as refractive error is concerned, we find - - as expected - - that the ionospherically-induced bending at 1.0 GHz is quite small. Again the largest values are introduced within a narrow range of zenith angles for the case of a super-ionospheric satellite. The compilation of results is given in Appendix C.

The refractive effects are determined to be quite sensitive to the distribution of electrons along the ray path. We note that the error may exhibit one or more "extrema" along the path but may "relax" to another value as the path becomes extended and exits the ionospheric plasma. The ultimate value is of most importance for the situation we are analyzing in this report.

Bending errors of the order of 1 milliradian might arise in a number of geometric and climatological conditions. However these instances are expected to be quite rare. This is surely the case at the higher GPS frequencies of nominally 1.2 and 1.6 GHz.

5.0 Other Issues

Aside from TEC, the other major "ionospheric effect" is that arising from ionospheric inhomogeneities. The "worst case" conditions at L band would be expected to be observed over the equatorial sector following sunset and near solar maximum conditions. The worst case scenario was observed in a test conducted at Ascension Island in 1981 ... a time of extraordinary solar activity. According to Klobuchar [1981] conditions are unlikely to be much worse than those observed during that period.

Equatorial scintillation does not appear to be elevation dependent; at times three or more GPS downlinks experienced Rayleigh fading simultaneously. Some doppler cycle carrier slipping was observed and phase lock could not always be maintained during strong scintillation periods [See Klobuchar, 1981].

6.0 Preliminary Conclusions

The question of whether a single-frequency system will be satisfactory in the current context has been examined in this report. This context is that of placing one or a set of single-frequency GPS receivers on a satellite structure to allow for determination of satellite position and perhaps other factors such as orientation, etc.

As expected, at frequencies in the neighborhood of 1 GHz the absolute magnitude of single-frequency group-path-delay introduced by the ionosphere is much smaller than normally encountered in the VHF band. Likewise the amount of ionospheric refraction is a small number owing to the inverse square dependence of the effect with frequency. Naturally the effects at the nominal GPS frequencies are diminished even more. All of this was anticipated. The question was rather ..." is the anticipated single-frequency error small enough to allow for the deployment of a single-frequency system in space ; i.e., one which does not require substantial dynamic compensation ?".

For a restricted set of "look angles", errors in absolute range due to the ionosphere may be substantial for satellites (i.e., GPS receivers) which orbit above the sensible ionosphere (referred to as superionospheric satellites), but the importance of this error is diminished significantly if the accessed GPS (transmitting) satellites are located above the local horizontal. In this latter case, absolute errors of a few to about 15 nS might be expected for a wide range of "look angles" corresponding to "upward-looking" GPS receivers.

Again, for superionospheric satellites, there may be substantial excess group path delay errors for large zenith angles as suggested in the paragraph above. These errors are concentrated for paths below the horizontal (i.e.; zenith angle between 90 and 120 degrees). In these cases the errors may be up to 1340 nS at 1 GHz or about 523 nS at 1.6 GHz. That is the bad news! The good news is that avoidance of these large errors may be easily achieved through access of satellites in the GPS constellation which present "look angles" above the local horizontal.

For subionospheric satellites (i.e.; satellites orbiting at 100 km or so), the TEC errors are not too dissimilar from those which would be expected in typical earth-space paths. It is noteworthy however that the variation in this error is not as concentrated at the large ray zenith angles as it is in the superionospheric case. It is noteworthy that the TEC-induced errors for this subionospheric case cannot be largely avoided by careful selection of GPS (transmitter) assets. They can be minimized however by accessing only those GPS assets which present "look angles" within some prescribed corridor around local zenith. This corridor depends upon climatological conditions and the geographical location of the satellite receiving platform.

It is well recognized that full corrections for group path delay error cannot be made using statistical models however elegant. This includes the Ching-Chiu model, RADARC, ICED, or the Klobuchar (or BENT) models to name a few. A major difficulty is that models cannot cope with the omnipresent short-term ionospheric variability. Compensation of about 50% has been reported, but that is optimistic at times. This situation is why two-frequency ionospheric compensation is employed. Naturally if the ionospheric error is not too important a factor, but we still wish to limit it to a degree, a model may be used for this purpose. This is common practice for single-frequency terrestrial users of the GPS system.

Concerning the issue of models in the present case of spaceborne utilization of GPS, there are indeed be geometrical situations such that sufficient precision may be achieved in the single frequency context. These are most apparent in the case of superionospheric (receiver) systems where we can simply limit the accessed GPS (transmitter) systems to those well above the local horizontal. However, it is not anticipated that subionospheric systems can use the single-frequency system even if a model is used to limit the ultimate error magnitude. Nevertheless, if the satellite (receiver) system is imbedded in the ionosphere, the answer is different. Indeed, if the satellite is well above the peak of the F2 layer ionization, modelling begins to have a great deal more of charm as far as success in compensation is concerned. The ionosphere consists of roughly twice as many electrons above the F2 peak as below, and at about 100 km over the F2 peak altitude some 50% of the TEC has been encountered. Finally the variability of ionization is maximized near the F2 peak and drops markedly above the peak. Thus, for satellites located at (or above) 500 km altitude or so (the F2 peak being nominally 300 km in altitude), we expect the encountered TEC as well as its variability to be diminished. As a consequence of this, it must be said that modelling may indeed have a role to play. Unfortunately there is no verified model for the situation being examined. One could imagine such a model however.

As far as platform orientation determination is concerned, multiple single-frequency systems should serve the needs adequately. This is because, for all multiple paths from the satellite to a particular GPS satellite, the TEC will be essentially the same; the difference in path length is in essence only the free space difference. This means we can orient ourselves in 3D (with three receivers) with respect to a given GPS satellite. This orientation solution may be carried out for all GPS satellites which may be accessed. If we know where the GPS satellites are, we should have an excellent consistency check on orientation.

Another effect investigated was the issue of refractive error. As expected, the bending of the ray trajectory is slight at the frequencies involved. Nevertheless, we should observe deviations from rectilinear propagation of the order of a milliradian under some conditions. This observation would be expected to be maximized for high zenith angles where the vertical gradient of the encountered TEC is itself maximized. Generally, however, the effect is much less than this.

The following thought is left for consideration by the designer of a set of GPS receivers distributed on a single platform.

> Use one 2-frequency GPS receiver to resolve the TEC-induced error for selected satellites in the constellation. Perhaps this should be at the center of the platform. Use lighter single-frequency receivers everywhere else...with the ionospheric compensation passed from the centralized (not necessary to be central ... just convenient) 2-frequency GPS set.

Alternatively, one could locate an L1 receiver at the center of mass of the satellite and locate L2 receivers everywhere else. This would solve the TEC-ambiguity problem if the technique were realizable.

7.0 Future Proposed Plans

We would propose that further consideration be given to this topic or related ones.

The next logical step is to examine the single-frequency group path delay errors for actual paths. This is a simple procedure given access to the GPS constellation ephemeris data sets. In this way one could deduce the likelihood of pathological ray trajectories. We would still use quasi-rectilinear propagation through the Ching-Chiu model for this phase. For completeness, a comparison with the Klobuchar model would be made for those cases where a comparison is logical.

In the area of refractive error, one would like to incorporate 3-d ray tracing as opposed to the simulated 2-d ray tracing based upon the wedge refraction principle which was applied herein. This would be done in several phases, starting first with the exploitation of the Ching-Chiu model, but ultimately being directed toward the use of other more sophisticated models such as ICED, the International Reference Ionosphere (IRI) ,or those contained in either IONCAP or RADARC. Certain strides in this area have already been completed in the context of another program.

Another area which should be addressed is that of providing for TEC compensation through updating the Klobuchar (or similar) algorithm with live data. This may be attractive in certain instances. It is remarked that the Klobuchar algorithm must be modified for the case of the spaceborne geometry. In other words, a new model must be developed. The new model would include the novel features of an "ionospherically-imbedded" as well as a superionospheric satellite.

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APPENDIX A

COMPUTER CODE LISTINGS

1. PROGRAM GPSTST
2. SUBROUTINE CHNCHU
3. SUBROUTINE BEGIN
4. SUBROUTINE MAGFLD
5. SUBROUTINE MON1
6. PROGRAM GPS_FAST
7. SUBROUTINE DATAIN
8. SUBROUTINE START
9. SUBROUTINE MFIELD
10. SUBROUTINE ELDENS

```
      PROGRAM GPSTST
C
C THIS IS THE MAIN ROUTINE FOR THE GPS TEST.
C
      COMMON /CGM/ AZIM,XLAT,XLON,XHT,HUR,DAY,TIM,XPN
      DIMENSION ANG(10), TEC(10)
      DATA D2R/0.01745329/
C
      OPEN (UNIT=10,FILE='OPUT',TYPE='NEW')
C
500   TYPE 100
100   FORMAT (5X,'SATELLITE LAT. & LON. (DEG.) = ',$)
      ACCEPT 110, RLAT, RLON
110   FORMAT (2F10.0)
      XLAT = RLAT * D2R
      IF (RLON .LT. 0.) THEN
        RLON = RLON + 360.
      END IF
      XLON = RLON * D2R
      TYPE 120
120   FORMAT (15X,'ALTITUDE (KM) = ',$)
      ACCEPT 110, XHT
      TYPE 130
130   FORMAT (5X,'ENTER DATE (MM,DD,YYYY) = ',$)
      ACCEPT 140, MO,IDA,IYR
140   FORMAT (3I7)
      IF (IYR .LT. 1900) THEN
        IYR = IYR + 1900
      END IF
      TIM = FLOAT (IYR)
      IF (MO .GT. 5) THEN
        IAD = (MO / 2) - 2
      ELSE
        IAD = 0
      END IF
      DAY = FLOAT ((MO - 1)* 30 + IDA + IAD)
      TYPE 150
150   FORMAT (5X,'LOCAL TIME OF DAY (0000 - 2400) = ',$)
      ACCEPT 160, HR, FHR
160   FORMAT (2F2.0)
      HUR = HR + FHR / 60.
      TYPE 180
180   FORMAT (5X,'SUNSPOT NUMBER = ',$)
      ACCEPT 110, XPN
      IF (XPN .GT. 10.) THEN
        XPN = XPN / 100.
      END IF
      CALL MON1 (RLAT,RLON,XHT,MO,IDA,IYR,HR,FHR,XPN)
C
      BZM = 0.
      DO 510  NN=1,6
      AZIM = BZM * D2R
C
      CALL CKNCHU (ANG,TEC,K)
      CALL MON2 (BZM,ANG,TEC,K)
C
      BZM = BZM + 60.
510   CONTINUE
      STOP
      END
```

```
      SUBROUTINE  CHNCHU (ANG,TEC,K)
C
C  THIS ROUTINE CALCULATES THE TOTAL ELECTRON CONTENT (TEC) ALONG A GIVEN
C  PATH FROM A SATELLITE AND IS SCALED BY 10 ** 11 ELECTRONS PER CUBIC METER.
C  THE EQUATIONS FOR THIS MODEL WERE OBTAINED FROM THE ARTICLE IN THE
C  JOURNAL OF ATMOS. & TERRES. PHYSICS (1973) BY B K CHING & Y T CHIU AND
C  ERRATA SHEET IN SAME JOURNAL (1974).
C
C  ORIGINAL PROGRAM  C G MYERS  CODE 7900 NRL  1976
C  REVISED           C G MYERS  BENDIX  FOR CODE 4180 NRL  1987
C
C  PARAMETERS
C     XLAT = SATELLITE LATITUDE (+ = N)
C     XLON =           LONGITUDE (+ = E)
C     XHT  =           ALTITUDE (KM)
C     HUR  =           LOCAL TIME (0 - 24 HR)
C     DAY  = DAY OF THE YEAR
C     TIM  = YEAR
C     XPN  = SUN SPOT NUMBER SCALED BY 100 (0 - 2)
C     TEC  = TOTAL ELECTRON CONTENT FOR GIVEN PATH
C     HGT  = MIP ALTITUDE
C     XRQ  = SIN PATH INCIDENCE ANGLE AT MIP
C     XC1  = SIN ANGLE BETWEEN SATELLITE AND MIP RADIUS VECTORS
C     COLI = COS MIP CO-LATITUDE
C     EMN  = MIP LONGITUDE
C     EMT  = MIP LATITUDE
C     HR   = MIP LOCAL TIME (RADIANS)
C     DY   = MIP DAY (MONTHS FROM 15 DEC.)
C
      COMMON /CGM/ AZIM,XLAT,XLON,XHT,HUR,DAY,TIM,XPN
      COMMON /MF/ TG(100),TH(100)
      COMMON /PS/ PI(7),XPC(8),DDY
C
      DIMENSION ANG(10),TEC(10)
C
      DATA CN/7.955E-4/,RD/6378.2/,DFA/1.0E-7/,XP/2.41339/
C
      CAZ = COS (AZIM)
      XAZ = SIN (AZIM)
      CRT = COS (XLAT)
      XRT = SIN (XLAT)
      CALL BEGIN (DV,DX,HOR)
C
C
      XGT = XHT + RD
      DANG = - ACOSD ((RD + 50.)/ XGT)
      DANG = NINT (DANG / 5.)* 5.
      DANG = DANG * 0.01745329
      K=0
      DO WHILE (DANG .LT. 0.175)
        XDNG = SIN (DANG)
        CDNG = COS (DANG)
        RNG = -5.
        HGT = 0.
        K = K + 1
        ANG(K) = DANG
        TEC(K) = 0.
        DO WHILE (HGT .LT. 2001)
          RNG = RNG + 10.
          EAR = XGT * XGT + RNG * RNG + 2.0 * XGT * RNG * XDNG
```

```
            HGT = SQRT (EAR)
            AOR = RD / HGT
C*          XRQ = XGT * CDNG / HGT
C*          CRQ = SQRT (1.- XRQ * XRQ)
            XC1 = RNG * CDNG / HGT
            CC1 = SQRT (1.- XC1 * XC1)
            HGT = HGT - RD
            COLI = CC1 * XRT + XC1 * CRT * CAZ
            XOLI = SQRT (1.- COLI * COLI) + 1.E-8
            EMT = ASIN (COLI)
C
            IF (ABS (XAZ) .LE. 0.02) THEN
              IF (XC1 .LE. CRT) THEN
                DLON = 0.
              ELSE
                DLON = PI(1)
              END IF
            ELSE
              DLON = ASIN (XC1 * XAZ / XOLI)
            END IF
C
            EMN = AMOD ((XLON + DLON), PI(2))
            DY = DV
            HR = HOR + DLON
            IF (HR .LT. 0.) THEN
              HR = HR + PI(2)
              DY = DY -  DDY
            ELSE IF (PI(2) .LT. HR) THEN
              HR = HR - PI(2)
              DY = DY + DDY
            END IF
            CHR = COS (HR)
            XHR = SIN (HR)
C
            CALL MAGFLD (AOR,EMN,COLI,XOLI,EML)
            XLM = SIN (EML)
            XLM2 = XLM * XLM
            CLM = COS (EML)
            ALM = ABS (EML)
C
C  AXD = SOLAR DECLINATION ANGLE
            IF (DY .NE. DX) THEN
              DX = DY
              XXD = 0.39795 * SIN (PI(6) * (DX - 3.1703))
              AXD = ASIN (XXD)
              CXD = COS (AXD)
            END IF
C  ZTA AND CAB = SEASONAL ANOMALIES
            ZTA = XXD * XLM
            CAB = COS (EML + AXD * CHR)
C  CKI = COS SOLAR ZENITH ANGLE
            CKI = COLI * XXD - XOLI * CXD * CHR
            WD = SQRT (ABS (CKI))
            WD = SIGN (WD,CKI) - 1.
            VT = XOLI - COS (EMT + AXD * CHR)
C  E LAYER CALCS
C  E LAYER = 0 ABOVE 350 KM
C
C  ZEA = E LAYER PROFILE FUNCTION
C  ENA =         ELECTRON DENSITY
```

```
          EAR = (HGT - 110.) / 10.0
          ZEA = EXP (0.5 * (1. - EAR - EXP (-EAR))) * 1.36
          IF (DFA .LE. ZEA) THEN
            ENA = ZEA * XPC(3) * EXP (0.4 * WT) * EXP (2. * WD)
          ELSE
            ENA=0.
          END IF
C
C  ZEB = F1 LAYER PROFILE FUNCTION
C  ENB =         ELECTRON DENSITY
          EAR = (HGT - 180.) / 34.0
          ZEB = EXP (0.5 * (1. - EAR - EXP (-EAR))) * 2.44
          IF(DFA .LE. ZEB) THEN
            ENB = ZEB * XPC(4) * EXP (0.25 * WT) * EXP (XPC(7) * WD)
          ELSE
            ENB = 0
          END IF
C
C  CHECK FOR F2 LAYER CALCS   F2 LAYER DENSITY = 0 BELOW 120 KM
C  CALC F2 LAYER PROFILE FUNCTION ZED
          EAR = HR - ALM * 4.5
          P3 = 240.- 30.* COS (EAR)+ (75. + 83. * ZTA * CLM)* XPN
          IF (P3 .LT. HGT) THEN
            EAR = P3
          ELSE
            EAR = HGT
          END IF
          H3 = 20.0 + 0.1 * EAR
          EAR = (HGT - P3) / H3
          ZEC = EXP (1.0 - EAR - EXP (-EAR))
C  V3  = POLAR FUNCTION
C  F3  = FOLDING FUNCTION
          IF(DFA .LE. ZEC) THEN
            CAR = HR - 0.87266
            V3 = EXP (CAB) * (2.+ XPN + 0.5 * COS (CAR))
            IF (PI(3) .LE. ALM) THEN
              ENC = V3 * ZEC
            ELSE
              EAR = (SIN (PI(3) - ALM) * 2.92) **6
              F3 = EXP (- EAR)
              V3 = V3 * F3
              F3 = 1.0 - F3
C  S3 = SOLAR CYCLE FUNCTION
              IF(1.1 .LT. XPN) THEN
                S3 = XPC(5)
              ELSE
               S3 = 2.41 + 1.53 * XLM2 * (XPC(5) - 2.41)
              END IF
C  D3 = DIURNAL FUNCTION
              EAR = (COS (0.5 * CAR)) ** 2
              D3 = EXP (-2.2 * EAR)
              GAR = (COS (HR + PI(4))) ** 2
              D3 = (0.9 + 0.32 * ZTA) * (1. + ZTA * GAR) * D3
C  EL = LATITUDINAL FUNCTION
              EAR = COS (0.5 * EML * (XHR - 1.))
              EL = EXP (3. * EAR) * (0.7 + 0.5 * XLM2)
C  T3 = ANNUAL FUNCTION
              T3 = EXP ((CLM - CAB) * XPC(6)) * 0.7
              EAR = COS (PI(5) * (DY - 4.3068)) * XPC(2)
              T3 = T3 * (1. + 0.178 * EAR / S3)
```

```
C  Y3 = PART OF T3
              Y3 = 0.2 * COS (PI(6) * (DY - 1.))
              Y3 = (1. + 0.6 * COS (PI(5) * (DY - 3.9452))) * Y3
              Y3 = (1. - SIN (ALM - PI(6))) * Y3
              Y3 = (0.13 - 0.06 * SIN (ALM - PI(7))) * COS (PI(5) *
     1             (DY - 4.4504)) + Y3
              EAR = 1.0 - CHR
              IF (EAR .EQ. 0.) THEN
                T3 = T3 + Y3 / S3
              ELSE
                DAR = (CLM * CXD - XLM * XXD) ** 3
                XBR = ABS (XLM)
                T3 = T3 + (Y3 -(0.15 + 0.3 * XBR)* DAR * SQRT
     2               (SQRT(EAR)))/ S3
              END IF
C  E3 = EQUATORIAL ANOMALY FUNCTION
C  G3 = PART OF E3
              EAR = (COS (HR - 4.0099) + 1.0) * 0.25
              G3 = EXP (EAR) * XPC(8) + 1.0
              EAR = CLM * CLM
              CAR = EAR ** 4
              EAR = CAR * EAR
              E3 = (1. - 0.4 * EAR)* (1. + 0.6 * EAR * GAR) * CAR * G3
              EAR = (COS (ALM - 0.2618)) ** 12
              E3  = EAR * E3
C  ENC = F2 LAYER ELECTRON DENSITY
              ENC = ZEC * (V3 + F3 * S3 * D3 * EL * T3 * E3) * 0.66
            END IF
          ELSE
            ENC = 0
          END IF
C
C  SUM DENSITIES AND CALC CONTENT PER SQUARE METER
          EAR = ENA + ENB + ENC
          IF (EAR .LT. DFA) THEN
            IF (HGT .GT. 1001.) THEN
              HGT = HGT + 2000.
            END IF
          ELSE
            TEC(K) = EAR + TEC(K)
          END IF
C**       CALL MON6 (HGT,EAR,RNG)
        END DO
        DANG = DANG + 0.08726645
      END DO
      RETURN
      END
```

```
C
      SUBROUTINE BEGIN (DV,DX,HOR)
C
      COMMON /CGM/ AZIM,XLAT,XLON,XHT,HUR,DAY,TIM,XPN
      COMMON /MF/ TG(100),TH(100)
      COMMON /PS/ PI(7),XPC(8),DDY
C
      DIMENSION H(100),G(100),HT(100),GT(100),SMT(100),FAR(4)
      DATA XR2/1.41421356/, SMT(1)/1.0/, XPC(1)/-5./
C
C  THIS SUBROUTINE SETS UP THE MAGNETIC FIELD ARRAYS AND
C  CALCULATES THE SUN SPOT NUMBER AND PI FUNCTIONS
C
      IF (SMT(1) .GT. 0.) THEN
        DDY = 0.0328767
C  CALC (PI/N) CONSTANTS
        PI(1) = 3.14159265
        PI(2) = PI(1) * 2.0
        PI(3) = PI(1) / 2.0
        PI(4) = PI(3) / 2.0
        PI(5) = PI(1) / 3.0
        PI(6) = PI(5) / 2.0
        PI(7) = PI(5) / 3.0
C  CALC FILTER ARRAY
        SMT(1) = -1.0
        DO 200  N = 2,10
          SMT(N) = SMT(N-1) * FLOAT (2 * N - 3) / FLOAT (N- 1)
          DO 200  M = 2,N
            K = (M - 1) * 10 + N
            EAR = SQRT (FLOAT (N - M + 1) / FLOAT (N + M - 2))
            SMT(K) = SMT(K-10) * EAR
            IF (M .EQ. 2) SMT(K) = SMT(K) * XR2
200     CONTINUE
        OPEN(UNIT=13,FILE='LEMAG',TYPE='OLD')
C  READ IN MAGNETIC FIELD DATA  T2R = DATE OF DATA
        READ (13, 210) T2R
210     FORMAT (2X,F8.0)
        TLST = T2R
220     READ (13, 230,END=240) N, M, (FAR(I),I = 1, 4)
230     FORMAT (2I3,4F7.0)
C  CHECK FOR END OF DATA
        K = (M - 1) * 10 + N
        EAR = SMT(K)
        G(K)  = FAR(1) * EAR
        H(K)  = FAR(2) * EAR
        GT(K) = FAR(3) * EAR
        HT(K) = FAR(4) * EAR
        GO TO 220
240     CLOSE (13)
      END IF
C  CHECK IF NEW MAGNETIC FIELD DATA NEEDED. IF SO, DO CALCS
      TNEW = TIM + (DAY - 15.)/ 365.
      IF (TNEW .NE. TLST) THEN
        T = TNEW - T2R
        DO 250  N = 2,9
          DO 250  M = 1,N
            K = (M - 1) * 10 + N
            TG(K) = G(K) + GT(K) * T
            TH(K) = H(K) + HT(K) * T
250     CONTINUE
```

```
          TLST = TNEW
        END IF
C   CONVERT DAY AND HOUR TO PROPER FORM
        DX = 0
        DV = (DAY + 16.0) * DDY
        IF (DV .EQ. 0.) DX = PI(6)
        HOR = HUR * PI(6) * 0.5
C   CALC SUNSPOT NUMBER FUNCTIONS
        IF (XPN .NE. XPC(1)) THEN
          XPC(1) = XPN
          IF (XPN .EQ. 0.) THEN
            XPC(2) = 0.
            XPC(6) = 1.3
            XPC(3) = 1.0
            XPC(4) = 1.0
            XPC(5) = 1.0
            XPC(7) = 1.0
            XPC(8) = 1.0
          ELSE
            XPC(2) = XPN * XPN
            XPC(3) = SQRT (1.0 + 1.15 * XPN)
            XPC(4) = SQRT (((0.25 * XPN) + 1.24) * XPN + 1.0)
            XPC(5) = ((((0.05 * XPN) + 0.204) * XPN) + 1.) * XPN + 1.0
            XPC(6) = ((0.069 * XPN) + 0.139) * XPC(2) + 1.3
            XPC(7) = LOG (1.0 + 30.0 * XPN) * 0.5 + 1.0
            XPC(8) = 1.0 + 0.2 * XPN + SQRT (XPN) * 0.6
          END IF
        END IF
        RETURN
        END
```

```
      SUBROUTINE MAGFLD(AOR,EMN,COLI,XOLI,EML)
C
C  THIS SUBROUTINE CALCULATES THE MAGNTEIC LATITUDE OF A LOCATION.
C
      COMMON /MF/ TG(100),TH(100)
      COMMON /PS/ PI(7),XPC(8),DDY
C
      DIMENSION P(100),DP(100),SP(10),CP(10)
      DATA CN/7.955E-4/, P(1)/1./, CP(1)/1./
C
C  CLEAR MAG FIELD VECTORS
      GME = 0.
      GMN = 0.
      GMV = 0.
C
C  MAGNETIC FIELD CALCS
      CP(2) = COS (EMN)
      SP(2) = SIN (EMN)
      DO 121  K = 3,10
        SP(K) = SP(2) * CP(K-1) + CP(2) * SP(K-1)
        CP(K) = CP(2) * CP(K-1) - SP(2) * SP(K-1)
121   CONTINUE
      AR = AOR * AOR
      DO 129  N = 2,7
        AR = AOR * AR
        DO 129  M = 1,N
C  CALC ARRAY INDEX
          K = (M - 1) * 10 + N
          IF (M .EQ. N) THEN
            DP(K) = XOLI * DP(K-11) + COLI * P(K-11)
            P(K) = XOLI * P(K-11)
          ELSE
            P(K) = COLI * P(K-1)
            DP(K) = COLI * DP(K-1) - XOLI * P(K-1)
            IF (K .EQ. 3) P(3) = P(3) - 0.333333333
          END IF
127       PAR = P(K) * AR
          EAR = TG(K) * CP(M) + TH(K) * SP(M)
C  NORTH MAGNETIC VECTOR
          GMN = GMN - EAR * DP(K) * AR
          IF (M .EQ. 2 .OR. M .EQ. 3) THEN
C  EAST MAGNETIC VECTOR
            GME = GME - (TG(K) * SP(M) - TH(K) * CP(M)) * PAR
     1            * FLOAT (M - 1)
          END IF
128       IF (N .EQ. 2 .OR. N .EQ. 3) THEN
C  VERTICAL MAGNETIC VECTOR
            GMV = GMV + EAR * PAR * FLOAT (N)
          END IF
129   CONTINUE
      GME = GME * CN / XOLI
      GMN = GMN * CN
      GMV = GMV * CN
C  MAGNETIC VECTOR AT MIP
      GMT = SQRT (GMV * GMV + GMN * GMN + GME * GME)
C  CALC MAGNETIC LATITUDE
      EAR = GMV / GMT
      IF (EAR .EQ. 0.) THEN
        EML = 0.
      ELSE
```

```
  IF (EAR .LT. 1.) THEN
    EML = ATAN (TAN (ASIN (EAR)) * 0.5)
  ELSE
    EML = SIGN (PI(3),EAR)
  END IF
END IF
RETURN
END
```

```
C
      SUBROUTINE MON1 (RLT,RLN,XHT,MO,IDA,IYR,HR,FHR,XPN)
C
C  THIS SUBROUTINE DOES THE PRINTING FOR GPSTST.
C
      XPA = XPN * 100.
      IY = IYR - 1900
      IR = NINT (HR)
      IFR = NINT (FHR)
      WRITE (10,100) RLT,RLN,XHT
100   FORMAT (5X,'SATELLITE POSITION'//5X,'LAT ',F6.2,5X,
     1       'LON ',F7.2,5X,'ALT ',F5.0,' KM')
      WRITE (10,200) MO,IDA,IY,IR,IFR
200   FORMAT (5X,'DATE AND TIME  ',2(I2.2,'/'),I2,3X,2I2.2,' HRS')
      ZPN = XPN * 100.
      WRITE (10,300) ZPN
300   FORMAT (5X,'SUNSPOT NUMBER IS ',F5.0)
      END
C
C
C
      SUBROUTINE MON2 (BZM,ANG,TEC,K)
C
      DIMENSION ANG(10),TEC(10)
C
      WRITE (10,100) BZM
100   FORMAT (//10X,'HORZ ANG',5X,'TEC',10X,'NSEC',6X,'AZIM = ',F5.0/)
      DO 200  N=1,K
        TOT = TEC(N) * 0.1
        DEL = TOT * 1.34
        DIP = ANG(N) / 0.01745
        WRITE (10,120) DIP,TOT,DEL
120     FORMAT (12X,F4.0,2F12.1)
200   CONTINUE
      END
```

```
C*
      PROGRAM GPS_FAST
C*
C*  THIS ROUTINE COMPUTES THE PATH DELAY AND RAY DEFLECTION BETWEEN TWO
C*  SATELLITES.  THE DELAY IS IN NANOSECONDS AND THE DEFLECTION IS IN
C*  MILLIRADIANS AND METERS.
C*
C*  WRITTEN FEBRUARY 1988 BY C G MYERS, BENDIX FIELD ENGINEERING, FOR
C*  NAVAL RESEARCH LABORTORY CODE 4180
C*
      COMMON /EDP/ COLI,DY,EML,EMT,HGT,HR,TEC,XOLI
      COMMON /DI/ IDY,IFHR,IHR,IYR,MO,XHT,XLAT,XLON
      COMMON /ST/ DAY,DV,HOR,HUR,TIM,XPN
      COMMON /MF/ TG(100),TH(100)
      COMMON /PS/ PI(7),XPC(8),DDY
C*
      CHARACTER*25 OPUT
C*
      DATA    D2R/0.01745329/          ! DEGREES TO RADIANS
      DATA    FRQ/1.0/                 ! FREQUENCY (GHZ)
      DATA    RD/6378.2/               ! EARTH RADIUS (KM)
      DATA    STEP/10./                ! RANGE STEP (KM)
      DATA OPUT/'USD1:[MYERS.RONB]GFST.OUT'/  ! OUTPUT FILE
C*
      OPEN (UNIT=10,FILE=OPUT,TYPE='NEW')
      WRITE (10,100)                   ! WRITE HEADER
100   FORMAT (4X,'**************************************'/4X,
     1        '*        GPS TEST     FAST TRACE       *'/4X,
     2        '*    CHING-CHIU IONOSPHERIC MODEL      *'/4X,
     3        '**************************************'//)
C*
      CALL DATAIN                              ! GET INPUT DATA
C*
      IF (XPN .GT. 20) THEN                    ! SUNSPOT NUMBER
        YPN = XPN
        XPN = XPN / 100.
      ELSE
        YPN = XPN * 100.
      END IF
C*
      WRITE (10,110) XLAT,XLON,XHT,MO,IDY,IYR,IHR,IFHR,YPN
110   FORMAT (5X,'SATELLITE:',F6.0,F6.0,F8.0,' KM ALT'/
     1        5X,'DATE-TIME:',I5.2,2('/',I2.2),6X,2I2.2,' HOURS'/
     3        5X,'FREQUENCY:    1.0 GIGAHERTZ'/
     4        5X,'SUNSPOT NUMBER:',F7.0//)
      WRITE (10,130)
130   FORMAT (3X,'AZIM',5X,'ELEV',6X,'DELAY',6X,'ANGLE',4X,'DISTANCE'/
     1        4X,'DEG',6X,'DEG',6X,'NSECS',6X,'MRADS',4X,' METERS'/)
C*
      FSQ = FRQ * FRQ
      RLAT = XLAT * D2R                        ! SATELLITE LATITUDE
      CRT = COS (RLAT)
      XRT = SIN (RLAT)
      RLON = XLON * D2R                        ! SATELLITE LONGITUDE
      XGT = XHT + RD                           !           RADIUS VECTOR
C*
      CALL START
C*
      DO 500  KA=1,6
      B2M = 60. * FLOAT (KA - 1)               ! GPS DIRECTION
```

```
      AZIM = BZM * D2R
      XAZ = SIN (AZIM)
      CAZ = COS (AZIM)
C*
      IF (XHT .LT. 200) THEN                      ! SATELLITE ALTITUDE
        DANG = -10.                               ! ELEVATION ANGLE
      ELSE
        DANG = -35.
      END IF
      DO 400  KD=1,4
      DANG = DANG + 5.
      EAR = DANG * D2R
      XDNG = SIN (EAR)
      CDNG = COS (EAR)
C*
      DLY = 0.
      SEP = 0.
      SHT = 0.
      RNG = 0.
      HGT = 0.
C*
      DO WHILE (HGT .LT. 1500.)
        RNG = RNG + STEP                          ! DIST FROM SATELLITE
        EAR = XGT * XGT + RNG * RNG + 2.0 * XGT * RNG * XDNG
        HGT = SQRT (EAR)                          ! MIP RADIUS VECTOR
        AOR = RD / HGT
        XRQ = XGT * CDNG / HGT
C*      CRQ = SQRT (1.- XRQ * XRQ)
        XC1 = RNG * CDNG / HGT
        CC1 = SQRT (1.- XC1 * XC1)
        HGT = HGT - RD                            ! PATH ALTITUDE
        COLI = CC1 * XRT + XC1 * CRT * CAZ
        XOLI = SQRT (1.- COLI * COLI) + 1.E-8
        EMT = ASIN (COLI)                         ! MIP LATITUDE
C*
        IF (ABS (XAZ) .LE. 0.01) THEN
          IF (XC1 .LT. CRT) THEN
            DLON = 0.
          ELSE
            DLON = PI(1)
          END IF
        ELSE
          DLON = ASIN (XC1 * XAZ / XOLI)          ! DELTA LONGITUDE
        END IF
C*
        EMN = AMOD ((RLON + DLON),PI(2))          ! MIP LONGITUDE
        DY = DV                                   ! DAY OF YEAR (RAD)
        HR = HOR + DLON                           ! TIME OF DAY (RAD)
        IF (HR .LT. 0.) THEN
          HR = HR + PI(2)
          DY = DY - DDY
        ELSE IF (PI(2) .LT. HR) THEN
          HR = HR - PI(2)
          DY = DY + DDY
        END IF
C*
C* GET MID VALUE
        CALL MFIELD (AOR,EMN)                     ! GET MAGNETIC FIELD
        CALL ELDENS                               ! GET ELECTRON DENSITY
        TMID = TEC                                ! DENSITY ON PATH
```

```
C*
C* GO UP 100 METERS
           HGT = HGT + 0.10
           AUR = RD /(RD + HGT)
           CALL MFIELD (AUR,EMN)
           CALL ELDENS
           TUPP = TEC                             ! DENSITY ABOVE PATH
C*
C* TRY DOWN
           HGT = HGT - 0.20
           AUR = RD /(RD + HGT)
           CALL MFIELD (AUR,EMN)
           CALL ELDENS
           TDWN = TEC                             ! DENSITY BELOW PATH
C*
           DLY = DLY + 0.134 * TMID / FSQ         ! SUM PATH DELAY
           EAR = 2.025E-2 *(TDWN - TUPP)* XRQ * STEP / FSQ
           SEP = SEP + EAR                        ! SUM DEFLECTION DEGREES
           SHT = SHT + EAR * STEP                 !                 METERS
         END DO
C*
         IF (KD .EQ. 1) THEN                      ! WRITE ANSWERS
           WRITE (10,200) BZH,DANG,DLY,SEP,SHT
200        FORMAT (F7.0,F9.0,F11.2,2F11.3)
         ELSE
           WRITE (10,210) DANG,DLY,SEP,SHT
210        FORMAT (7X,F9.0,F11.2,2F11.3)
         END IF
400      CONTINUE
C*
         WRITE (10,450)
450      FORMAT (/)
500      CONTINUE
C*
         END
```

```
C*
      PROGRAM GPS_FAST
C*
C*  THIS ROUTINE COMPUTES THE PATH DELAY AND RAY DEFLECTION BETWEEN TWO
C*  SATELLITES.  THE DELAY IS IN NANOSECONDS AND THE DEFLECTION IS IN
C*  MILLIRADIANS AND METERS.
C*
C*  WRITTEN FEBRUARY 1988 BY C G MYERS, BENDIX FIELD ENGINEERING, FOR
C*  NAVAL RESEARCH LABORTORY CODE 4180
C*
      COMMON /EDP/ COLI,DY,EML,EMT,HGT,HR,TEC,XOLI
      COMMON /DI/ IDY,IFHR,IHR,IYR,MO,XHT,XLAT,XLON
      COMMON /ST/ DAY,DV,HOR,HUR,TIM,XPN
      COMMON /MF/ TG(100),TH(100)
      COMMON /PS/ PI(7),XPC(8),DDY
C*
      CHARACTER*25 OPUT
C*
      DATA    D2R/0.01745329/         ! DEGREES TO RADIANS
      DATA    FRQ/1.0/                ! FREQUENCY (GHZ)
      DATA    RD/6378.2/              ! EARTH RADIUS (KM)
      DATA    STEP/10./               ! RANGE STEP (KM)
      DATA OPUT/'USD1:[MYERS.RONB]GFST.OUT'/  ! OUTPUT FILE
C*
      OPEN (UNIT=10,FILE=OPUT,TYPE='NEW')
      WRITE (10,100)                  ! WRITE HEADER
100   FORMAT (4X,'**************************************'/4X,
     1         '*       GPS TEST    FAST TRACE       *'/4X,
     2         '*    CHING-CHIU IONOSPHERIC MODEL    *'/4X,
     3         '**************************************'//)
C*
      CALL DATAIN                               ! GET INPUT DATA
C*
      IF (XPN .GT. 20) THEN                     ! SUNSPOT NUMBER
        YPN = XPN
        XPN = XPN / 100.
      ELSE
        YPN = XPN * 100.
      END IF
C*
      WRITE (10,110) XLAT,XLON,XHT,MO,IDY,IYR,IHR,IFHR,YPN
110   FORMAT (5X,'SATELLITE:',F6.0,F6.0,F8.0,' KM ALT'/
     1        5X,'DATE-TIME:',I5.2,2('/',I2.2),6X,2I2.2,' HOURS'/
     3        5X,'FREQUENCY:   1.0 GIGAHERTZ'/
     4        5X,'SUNSPOT NUMBER:',F7.0//)
      WRITE (10,130)
130   FORMAT (3X,'AZIM',5X,'ELEV',6X,'DELAY',6X,'ANGLE',4X,'DISTANCE'/
     1        4X,'DEG',6X,'DEG',6X,'NSECS',6X,'MRADS',4X,' METERS'/)
C*
      FSQ = FRQ * FRQ
      RLAT = XLAT * D2R                         ! SATELLITE LATITUDE
      CRT = COS (RLAT)
      XRT = SIN (RLAT)
      RLON = XLON * D2R                         ! SATELLITE LONGITUDE
      XGT = XHT + RD                            !            RADIUS VECTOR
C*
      CALL START
C*
      DO 500  KA=1,6
      BZM = 60. * FLOAT (KA - 1)                ! GPS DIRECTION
```

```
         AZIM = BZM * D2R
         XAZ = SIN (AZIM)
         CAZ = COS (AZIM)
C*
         IF (XHT .LT. 200) THEN                      ! SATELLITE ALTITUDE
           DANG = -10.                               ! ELEVATION ANGLE
         ELSE
           DANG = -35.
         END IF
         DO 400  KD=1,4
         DANG = DANG + 5.
         EAR = DANG * D2R
         XDNG = SIN (EAR)
         CDNG = COS (EAR)
C*
         DLY = 0.
         SEP = 0.
         SHT = 0.
         RNG = 0.
         HGT = 0.
C*
         DO WHILE (HGT .LT. 1500.)
           RNG = RNG + STEP                          ! DIST FROM SATELLITE
           EAR = XGT * XGT + RNG * RNG + 2.0 * XGT * RNG * XDNG
           HGT = SQRT (EAR)                          ! MIP RADIUS VECTOR
           AOR = RD / HGT
           XRQ = XGT * CDNG / HGT
C*         CRQ = SQRT (1.- XRQ * XRQ)
           XC1 = RNG * CDNG / HGT
           CC1 = SQRT (1.- XC1 * XC1)
           HGT = HGT - RD                            ! PATH ALTITUDE
           COLI = CC1 * XRT + XC1 * CRT * CAZ
           XOLI = SQRT (1.- COLI * COLI) + 1.E-8
           EMT = ASIN (COLI)                         ! MIP LATITUDE
C*
           IF (ABS (XAZ) .LE. 0.01) THEN
             IF (XC1 .LT. CRT) THEN
               DLON = 0.
             ELSE
               DLON = PI(1)
             END IF
           ELSE
             DLON = ASIN (XC1 * XAZ / XOLI)          ! DELTA LONGITUDE
           END IF
C*
           EMN = AMOD ((RLON + DLON),PI(2))          ! MIP LONGITUDE
           DY = DV                                   ! DAY OF YEAR (RAD)
           HR = HOR + DLON                           ! TIME OF DAY (RAD)
           IF (HR .LT. 0.) THEN
             HR = HR + PI(2)
             DY = DY - DDY
           ELSE IF (PI(2) .LT. HR) THEN
             HR = HR - PI(2)
             DY = DY + DDY
           END IF
C*
C* GET MID VALUE
           CALL MFIELD (AOR,EMN)                     ! GET MAGNETIC FIELD
           CALL ELDENS                               ! GET ELECTRON DENSITY
           TMID = TEC                                ! DENSITY ON PATH
```

```
C*
C* GO UP 100 METERS
          HGT = HGT + 0.10
          AUR = RD /(RD + HGT)
          CALL MFIELD (AUR,EMN)
          CALL ELDENS
          TUPP = TEC                          ! DENSITY ABOVE PATH
C*
C* TRY DOWN
          HGT = HGT - 0.20
          AUR = RD /(RD + HGT)
          CALL MFIELD (AUR,EMN)
          CALL ELDENS
          TDWN = TEC                          ! DENSITY BELOW PATH
C*
          DLY = DLY + 0.134 * TMID / FSQ      ! SUM PATH DELAY
          EAR = 2.025E-2 *(TDWN - TUPP)* XRQ * STEP / FSQ
          SEP = SEP + EAR                     ! SUM DEFLECTION DEGREES
          SHT = SHT + EAR * STEP              !                METERS
        END DO
C*
        IF (KD .EQ. 1) THEN                   ! WRITE ANSWERS
          WRITE (10,200) BZM,DANG,DLY,SEP,SHT
200       FORMAT (F7.0,F9.0,F11.2,2F11.3)
        ELSE
          WRITE (10,210) DANG,DLY,SEP,SHT
210       FORMAT (7X,F9.0,F11.2,2F11.3)
        END IF
400     CONTINUE
C*
        WRITE (10,450)
450     FORMAT (/)
500     CONTINUE
C*
        END
```

```
      SUBROUTINE DATAIN
C*
C*  THIS SUBROUTINE READS THE COMMAND FILE TO OBTAIN SATELLITE POSITION AND
C*  ALTITUDE, DATE AND TIME, AND SUNSPOT NUMBER.
C*
C*  WRITTEN FEBRUARY 1988  C. G. MYERS BENDIX FIELD ENGINEERING FOR NAVAL
C*  RESEARCH LABORATORY CODE 4180.
C*
      COMMON /DI/ IDY,IFHR,IHR,IYR,MO,XHT,XLAT,XLON
      COMMON /ST/ DAY,DV,HOR,HUR,TIM,XPN
C*
      ACCEPT 110, XLAT, XLON                    ! GET SATELLITE POSITION
110   FORMAT (2F10.0)
      IF (XLON .LT. 0.) THEN
        XLON = XLON + 360.
      END IF
      ACCEPT 110, XHT
      ACCEPT 140, MO,IDY,IYR                    ! GET DATE
140   FORMAT (3I3)
      IF (IYR .GT. 100) THEN
        IYR = IYR - 1900
      END IF
      TIM = FLOAT (IYR) + 1900.
      IF (MO .GT. 5) THEN
        IAD = (MO / 2) - 2
      ELSE
        IAD = 0
      END IF
      DAY = FLOAT ((MO - 1)* 30 + IDY + IAD)
      ACCEPT 150, IHR, IFHR                     ! GET TIME
150   FORMAT (2I2)
      HUR = FLOAT (IHR) + FLOAT (IFHR)/ 60.
      ACCEPT 110, XPN                           ! GET SUNSPOT NUMBER
C*
      RETURN
      END
```

```
C*
      SUBROUTINE START
C*
C*  THIS SUBROUTINE SETS UP THE MAGNETIC FIELD ARRAYS AND
C*  CALCULATES THE SUN SPOT NUMBER AND PI FUNCTIONS
C*
C*  WRITTEN ?????
C*  MODIFIED FEBRUARY 1988  C. G. MYERS BENDIX FIELD ENGINEERING FOR NAVAL
C*  RESEARCH LABORATORY CODE 4180.
C*
      COMMON /ST/ DAY,DV,HOR,HUR,TIM,XPN
      COMMON /MF/ TG(100),TH(100)
      COMMON /PS/ PI(7),XPC(8),DDY
C*
      DIMENSION H(100),G(100),HT(100),GT(100),SMT(100),FAR(4)
      DATA XR2/1.41421356/, SMT(1)/1.0/, XPC(1)/-5./
C*
      IF (SMT(1) .GT. 0.) THEN
        DDY = 0.0328767
C*  CALC (PI/N) CONSTANTS
        PI(1) = 3.14159265                    ! PI
        PI(2) = PI(1) * 2.0                   ! 2 PI
        PI(3) = PI(1) / 2.0                   ! PI / 2
        PI(4) = PI(3) / 2.0                   ! PI / 4
        PI(5) = PI(1) / 3.0                   ! PI / 3
        PI(6) = PI(5) / 2.0                   ! PI / 6
        PI(7) = PI(5) / 3.0                   ! PI / 9
C*  CALC FILTER ARRAY
        SMT(1) = -1.0
        DO 200  N = 2,10
          SMT(N) = SMT(N-1) * FLOAT (2 * N - 3) / FLOAT (N- 1)
          DO 200  M = 2,N
            K = (M - 1) * 10 + N
            EAR = SQRT (FLOAT (N - M + 1) / FLOAT (N + M - 2))
            SMT(K) = SMT(K-10) * EAR
            IF (M .EQ. 2) SMT(K) = SMT(K) * XR2
200     CONTINUE
        OPEN(UNIT=13,FILE='LEMAG',TYPE='OLD')
C*  READ IN MAGNETIC FIELD DATA  TZR = DATE OF DATA
        READ (13, 210) TZR
210     FORMAT (2X,F8.0)
        TLST = TZR
220     READ (13, 230,END=240) N, M, (FAR(I),I = 1, 4)
230     FORMAT (2I3,4F7.0)
C*  CHECK FOR END OF DATA
        K = (M - 1) * 10 + N
        EAR = SMT(K)
        G(K)  = FAR(1) * EAR
        H(K)  = FAR(2) * EAR
        GT(K) = FAR(3) * EAR
        HT(K) = FAR(4) * EAR
        GO TO 220
240     CLOSE (13)
      END IF
C*  CHECK IF NEW MAGNETIC FIELD DATA NEEDED, IF SO, DO CALCS
      TNEW = TIM + (DAY -15.)/ 365.
      IF (TNEW .NE. TLST) THEN
        T = TNEW - TZR
        DO 250  N = 2,9
          DO 250  M = 1,N
```

```
              K = (M - 1) * 10 + N
              TG(K) = G(K) + GT(K) * T
              TH(K) = H(K) + HT(K) * T
250         CONTINUE
          END IF
C*  CONVERT DAY AND HOUR TO PROPER FORM
          DV = (DAY + 16.0) * DDY
          HOR = HUR * PI(6) * 0.5
C*  CALC SUNSPOT NUMBER FUNCTIONS
          IF (XPN .NE. XPC(1)) THEN
            XPC(1) = XPN                              ! SUNSPOT NUMBER
            IF (XPN .EQ. 0.) THEN
              XPC(2) = 0.
              XPC(6) = 1.3
              XPC(3) = 1.0
              XPC(4) = 1.0
              XPC(5) = 1.0
              XPC(7) = 1.0
              XPC(8) = 1.0
            ELSE
              XPC(2) = XPN * XPN
              XPC(3) = SQRT (1.0 + 1.15 * XPN)
              XPC(4) = SQRT (((0.25 * XPN) + 1.24) * XPN + 1.0)
              XPC(5) = ((((0.05 * XPN) + 0.204) * XPN) + 1.) * XPN + 1.0
              XPC(6) = ((0.069 * XPN) + 0.139) * XPC(2) + 1.3
              XPC(7) = LOG (1.0 + 30.0 * XPN) * 0.5 + 1.0
              XPC(8) = 1.0 + 0.2 * XPN + SQRT (XPN) * 0.6
            END IF
          END IF
C*
          RETURN
          END
```

```
C*
      SUBROUTINE MFIELD (AOR,EMN)
C*
C*  THIS SUBROUTINE CALCULATES THE MAGNTEIC LATITUDE OF A LOCATION.
C*
      COMMON /EDP/ COLI,DY,EML,EMT,HGT,HR,TEC,XOLI
      COMMON /MF/ TG(100),TH(100)
      COMMON /PS/ PI(7),XPC(8),DDY
C*
      DIMENSION P(100),DP(100),SP(10),CP(10)
      DATA CN/7.955E-4/, P(1)/1./, CP(1)/1./, SP(1)/0./
C*
C*  CLEAR MAG FIELD VECTORS
      GME = 0.                                 ! MAGNETIC VECTOR EAST
      GMN = 0.                                 !                 NORTH
      GMV = 0.                                 !                 VERTICAL
C*
C*  MAGNETIC FIELD CALCS
      CP(2) = COS (EMN)
      SP(2) = SIN (EMN)
      DO 121  K = 3,10
        SP(K) = SP(2) * CP(K-1) + CP(2) * SP(K-1)
        CP(K) = CP(2) * CP(K-1) - SP(2) * SP(K-1)
121   CONTINUE
      AR = AOR * AOR
      DO 129  N = 2,7
        AR = AOR * AR
        DO 129  M = 1,N
C*  CALC ARRAY INDEX
          K = (M - 1) * 10 + N
          IF (M .EQ. N) THEN
            DP(K) = XOLI * DP(K-11) + COLI * P(K-11)
            P(K) = XOLI * P(K-11)
          ELSE
            P(K) = COLI * P(K-1)
            DP(K) = COLI * DP(K-1) - XOLI * P(K-1)
            IF (K .EQ. 3) P(3) = P(3) - 0.333333333
          END IF
127       PAR = P(K) * AR
          EAR = TG(K) * CP(M) + TH(K) * SP(M)
C*  NORTH MAGNETIC VECTOR
          GMN = GMN - EAR * DP(K) * AR
          IF (M .EQ. 2 .OR. M .EQ. 3) THEN
C*  EAST MAGNETIC VECTOR
            GME = GME - (TG(K) * SP(M) - TH(K) * CP(M)) * PAR
     1            * FLOAT (M - 1)
          END IF
128       IF (N .EQ. 2 .OR. N .EQ. 3) THEN
C*  VERTICAL MAGNETIC VECTOR
            GMV = GMV + EAR * PAR * FLOAT (N)
          END IF
129   CONTINUE
      GME = GME * CN / XOLI
      GMN = GMN * CN
      GMV = GMV * CN
C*  MAGNETIC VECTOR AT MIP
      GMT = SQRT (GMV * GMV + GMN * GMN + GME * GME)
C*  CALC MAGNETIC LATITUDE
      EAR = GMV / GMT
      IF (EAR .EQ. 0.) THEN
```

```
        EML = 0.
      ELSE
        IF (EAR .LT. 1.) THEN
          EML = ATAN (TAN (ASIN (EAR)) * 0.5)
        ELSE
          EML = SIGN (PI(3),EAR)
        END IF
      END IF
C*
      RETURN
      END
```

```
C*
      SUBROUTINE  ELDENS
C*
C*  THIS SUBROUTINE CALCULATES THE ELECTRON DENSITY AT A POINT IN SPACE.
C*  THE OUTPUT OF THIS SUBROUTINE IS IN UNITS OF 10**11 ELECTRONS PER
C*  CUBIC METER.
C*
C*  WRITTEN 1976  C. G. MYERS  NAVAL RESEARCH LABORATORY CODE 7980
C*  MODIFIED FEBRUARY 1988  C. G. MYERS  BENDIX FIELD ENGINEERING FOR NAVAL
C*  RESEARCH LABORATORY CODE 4180.
C*
      COMMON /EDP/ COLI,DY,EML,EMT,HGT,HR,TEC,XOLI
      COMMON /PS/ PI(7),XPC(8),DDY
C*
      DATA DFA/1.0E-7/,DX/0./
C*
      CHR = COS (HR)                    ! HOUR FUNCTIONS
      XHR = SIN (HR)
      XLM = SIN (EML)                   ! MAGNETIC LATITUDE FUNCTIONS
      XLM2 = XLM * XLM
      CLM = COS (EML)
      ALM = ABS (EML)
C*
C*  AXD = SOLAR DECLINATION ANGLE
      IF (DY .NE. DX) THEN
        DX = DY
        XXD = 0.39795 * SIN (PI(6) * (DX - 3.1703))
        AXD = ASIN (XXD)                ! SOLAR DECLINATION ANGLE
        CXD = COS (AXD)
      END IF
C*  ZTA AND CAB = SEASONAL ANOMALIES
      ZTA = XXD * XLM
      CAB = COS (EML + AXD * CHR)
C*  CKI = COS SOLAR ZENITH ANGLE
      CKI = COLI * XXD - XOLI * CXD * CHR
      WD = SQRT (ABS (CKI))
      WD = SIGN (WD,CKI) - 1.
      WT = XOLI - COS (EMT + AXD * CHR)
C*
C*  E LAYER CALCS
C*  E LAYER = 0 ABOVE 350 KM
C*  ZEA = E LAYER PROFILE FUNCTION
C*  ENA =         ELECTRON DENSITY
      EAR = (HGT - 110.) / 10.0
      ZEA = EXP (0.5 * (1. - EAR - EXP (-EAR))) * 1.36
      IF (DFA .LE. ZEA) THEN
        ENA = ZEA * XPC(3) * EXP (0.4 * WT) * EXP (2. * WD)
      ELSE
        ENA=0.
      END IF
C*
C*  ZEB = F1 LAYER PROFILE FUNCTION
C*  ENB =         ELECTRON DENSITY
      EAR = (HGT - 180.) / 34.0
      ZEB = EXP (0.5 * (1. - EAR - EXP (-EAR))) * 2.44
      IF(DFA .LE. ZEB) THEN
        ENB = ZEB * XPC(4) * EXP (0.25 * WT) * EXP (XPC(7) * WD)
      ELSE
        ENB = 0
      END IF
```

```
C*
C*  CHECK FOR F2 LAYER CALCS
C*  F2 LAYER DENSITY = 0 BELOW 120 KM
C*  CALC F2 LAYER PROFILE FUNCTION ZEC
        EAR = HR - ALM * 4.5
        P3 = 240.- 30.* COS (EAR)+ (75. + 83. * ZTA * CLM)* XPC(1)
        IF (P3 .LT. HGT) THEN
          EAR = P3
        ELSE
          EAR = HGT
        END IF
        H3 = 20.0 + 0.1 * EAR
        EAR = (HGT - P3) / H3
        ZEC = EXP (1.0 - EAR - EXP (-EAR))
C*
C*  V3  = POLAR FUNCTION
C*  F3  = FOLDING FUNCTION
        IF(DFA .LE. ZEC) THEN
          CAR = HR - 0.87266
          V3 = EXP (CAB) * (2.+ XPC(1) + 0.5 * COS (CAR))
          IF (PI(3) .LE. ALM) THEN
            ENC = V3 * ZEC
          ELSE
            EAR = (SIN (PI(3) - ALM) * 2.92) **6
            F3 = EXP (- EAR)
            V3 = V3 * F3
            F3 = 1.0 - F3
C*
C*  S3 = SOLAR CYCLE FUNCTION
            IF(1.1 .LT. XPC(1)) THEN
              S3 = XPC(5)
            ELSE
              S3 = 2.41 + 1.53 * XLM2 * (XPC(5) - 2.41)
            END IF
C*
C*  D3 = DIURNAL FUNCTION
            EAR = (COS (0.5 * CAR)) ** 2
            D3 = EXP (-2.2 * EAR)
            GAR = (COS (HR + PI(4))) ** 2
            D3 = (0.9 + 0.32 * ZTA) * (1. + ZTA * GAR) * D3
C*
C*  EL = LATITUDINAL FUNCTION
            EAR = COS (0.5 * EML * (XHR - 1.))
            EL = EXP (3. * EAR) * (0.7 + 0.5 * XLM2)
C*
C*  T3 = ANNUAL FUNCTION
            T3 = EXP ((CLM - CAB) * XPC(6)) * 0.7
            EAR = COS (PI(5) * (DY - 4.3068)) * XPC(2)
            T3 = T3 * (1. + 0.178 * EAR / S3)
C*
C*  Y3 = PART OF T3
            Y3 = 0.2 * COS (PI(6) * (DY - 1.))
            Y3 = (1. + 0.6 * COS (PI(5) * (DY - 3.9452))) * Y3
            Y3 = (1. - SIN (ALM - PI(8))) * Y3
            Y3 = (0.13 - 0.06 * SIN (ALM - PI(7))) * COS (PI(5) *
        1        (DY - 4.4504)) + Y3
            EAR = 1.0 - CHR
            IF (EAR .EQ. 0.) THEN
              T3 = T3 + Y3 / S3
            ELSE
```

```
                 DAR = (CLM * CXD - XLM * XXD) ** 3
                 XBR = ABS (XLM)
                 T3 = T3 + (Y3 -(0.15 + 0.3 * XBR)* DAR * SQRT
     2                 (SQRT(EAR)))/ S3
               END IF
C*
C*   E3 = EQUATORIAL ANOMALY FUNCTION
C*   G3 = PART OF E3
               EAR = (COS (HR - 4.0099) + 1.0) * 0.25
               G3 = EXP (EAR) * XPC(8) + 1.0
               EAR = CLM * CLM
               CAR = EAR ** 4
               EAR = CAR * EAR
               E3 = (1. - 0.4 * EAR)* (1. + 0.6 * EAR * GAR) * CAR * G3
               EAR = (COS (ALM - 0.2618)) ** 12
               E3  = EAR * E3
C*
C*   ENC = F2 LAYER ELECTRON DENSITY
               ENC = ZEC * (V3 + F3 * S3 * D3 * EL * T3 * E3) * 0.66
             END IF
           ELSE
             ENC = 0
           END IF
C*
C*   SUM DENSITIES
           TEC = ENA + ENB + ENC
C*
           RETURN
           END
```

APPENDIX B

TABULAR OUTPUT FROM THE CHING-CHIU MODEL AS MODIFIED TO YIELD TEC AND EXCESS IONOSPHERIC GROUP-PATH-DELAY.

APPENDIX B

- PART 1 -

ALTITUDE:	100 km
SUNSPOT NUMBER:	0
LATITUDE:	40°N
LONGITUDE:	270°E
FREQUENCY:	1 GHz

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 03/21/87 0000 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	11.6	15.6	
0.	6.9	9.2	
5.	3.4	4.5	
10.	2.3	3.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	3.1	4.1	
0.	3.5	4.7	
5.	2.9	3.9	
10.	2.2	3.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	3.7	5.0	
0.	3.7	4.9	
5.	2.9	3.9	
10.	2.2	3.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	7.5	10.1	
0.	5.3	7.1	
5.	3.5	4.7	
10.	2.5	3.3	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	5.2	7.0	
0.	4.1	5.5	
5.	3.1	4.1	
10.	2.3	3.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	3.1	4.1	
0.	3.5	4.7	
5.	2.9	3.9	
10.	2.2	3.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 03/21/87 0600 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	16.1	21.5	
0.	14.4	19.3	
5.	8.5	11.4	
10.	5.9	7.9	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	12.4	16.6	
0.	12.9	17.3	
5.	9.6	12.9	
10.	7.0	9.4	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	13.6	18.2	
0.	13.3	17.8	
5.	9.8	13.1	
10.	7.1	9.5	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	11.0	14.7	
0.	10.5	14.1	
5.	8.0	10.7	
10.	5.9	8.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	5.5	7.4	
0.	6.5	8.7	
5.	5.5	7.4	
10.	4.4	5.9	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	4.4	5.9	
0.	6.0	8.1	
5.	5.3	7.1	
10.	4.3	5.7	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 03/21/87 1200 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	24.1	32.3	
0.	27.6	36.9	
5.	19.0	25.4	
10.	13.9	18.7	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	18.8	25.2	
0.	24.0	32.2	
5.	18.6	25.0	
10.	14.1	18.8	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	25.8	34.5	
0.	26.8	35.9	
5.	19.8	26.5	
10.	14.6	19.6	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	41.0	54.9	
0.	32.2	43.2	
5.	21.5	28.8	
10.	15.3	20.5	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	25.6	34.3	
0.	27.1	36.3	
5.	19.9	26.7	
10.	14.7	19.7	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	18.8	25.2	
0.	24.0	32.2	
5.	18.6	25.0	
10.	14.1	18.8	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 03/21/87 1800 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	14.4	19.3	
0.	11.9	16.0	
5.	7.8	10.4	
10.	5.8	7.7	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	4.4	5.9	
0.	6.0	8.1	
5.	5.3	7.1	
10.	4.3	5.7	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	7.8	10.5	
0.	7.1	9.5	
5.	5.7	7.6	
10.	4.4	5.9	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	28.7	38.5	
0.	16.4	22.0	
5.	9.5	12.8	
10.	6.4	8.6	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	19.6	26.3	
0.	14.9	20.0	
5.	10.2	13.7	
10.	7.2	9.7	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	12.4	16.6	
0.	12.9	17.3	
5.	9.7	12.9	
10.	7.0	9.4	

IMPACT OF THE GEOPLASMA ON A SPACEBORNE GPS RECEIVER SYSTEM

A Preliminary Study

John M. Goodman

Ionospheric Effects Branch
E.O.Hulburt Center for Space Research
Space Sciences Division

22 February 1988

NRL Memorandum Report

Naval Research Laboratory
Washington DC 20375-5000

```
***********************************
*      GPS TEST    FAST TRACE     *
*   CHING-CHIU IONOSPHERIC MODEL  *
***********************************
```

SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 06/21/87 1800 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	27.56	-0.060	-0.604
	0.	25.52	-0.033	-0.333
	5.	17.41	-0.007	-0.067
	10.	12.85	0.000	0.002
60.	-5.	13.82	-0.051	-0.511
	0.	19.01	-0.049	-0.493
	5.	15.60	-0.012	-0.117
	10.	12.04	-0.002	-0.018
120.	-5.	16.34	-0.046	-0.458
	0.	19.31	-0.048	-0.484
	5.	15.53	-0.012	-0.118
	10.	11.95	-0.002	-0.020
180.	-5.	44.50	-0.032	-0.324
	0.	30.31	-0.031	-0.312
	5.	19.08	-0.003	-0.031
	10.	13.26	0.002	0.016
240.	-5.	28.83	-0.045	-0.452
	0.	25.[illegible]	-0.041	-0.408
	5.	18.30	-0.006	-0.063
	10.	13.37	0.001	0.012
300.	-5.	21.17	-0.056	-0.565
	0.	23.67	-0.045	-0.451
	5.	17.96	-0.007	-0.073
	10.	13.32	0.001	0.010

```
************************************
*      GPS TEST     FAST TRACE      *
*  CHING-CHIU IONOSPHERIC MODEL     *
************************************
```

SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 09/21/87 0000 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	15.59	-0.012	-0.118
	0.	9.23	0.004	0.043
	5.	4.48	-0.001	-0.007
	10.	3.05	-0.001	-0.010
60.	-5.	4.13	-0.008	-0.078
	0.	4.68	-0.010	-0.102
	5.	3.86	-0.004	-0.040
	10.	2.96	-0.001	-0.014
120.	-5.	4.79	-0.007	-0.068
	0.	4.84	-0.010	-0.098
	5.	3.90	-0.004	-0.040
	10.	2.97	-0.001	-0.014
180.	-5.	9.01	-0.004	-0.045
	0.	6.64	-0.007	-0.074
	5.	4.54	-0.003	-0.027
	10.	3.20	-0.001	-0.009
240.	-5.	6.44	-0.005	-0.050
	0.	5.34	-0.009	-0.090
	5.	4.05	-0.004	-0.037
	10.	3.03	-0.001	-0.013
300.	-5.	4.15	-0.008	-0.078
	0.	4.70	-0.010	-0.102
	5.	3.88	-0.004	-0.040
	10.	2.98	-0.001	-0.014

```
************************************
*      GPS TEST    FAST TRACE      *
*  CHING-CHIU IONOSPHERIC MODEL    *
************************************
```

SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 09/21/87 0600 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	20.69	-0.030	-0.300
	0.	18.26	-0.014	-0.143
	5.	10.67	-0.002	-0.017
	10.	7.28	-0.001	-0.011
60.	-5.	16.55	-0.034	-0.339
	0.	17.19	-0.027	-0.271
	5.	12.83	-0.005	-0.048
	10.	9.34	0.001	0.008
120.	-5.	17.81	-0.032	-0.325
	0.	17.62	-0.026	-0.265
	5.	13.00	-0.005	-0.045
	10.	9.42	0.001	0.009
180.	-5.	13.29	-0.021	-0.215
	0.	12.93	-0.024	-0.238
	5.	9.88	-0.007	-0.069
	10.	7.37	-0.002	-0.016
240.	-5.	7.10	-0.017	-0.171
	0.	8.51	-0.023	-0.232
	5.	7.28	-0.009	-0.091
	10.	5.78	-0.004	-0.036
300.	-5.	5.90	-0.018	-0.180
	0.	8.03	-0.024	-0.238
	5.	7.08	-0.009	-0.094
	10.	5.68	-0.004	-0.037

```
***********************************
*      GPS TEST     FAST TRACE    *
*  CHING-CHIU IONOSPHERIC MODEL   *
***********************************
```

SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 09/21/87 1200 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	32.14	-0.098	-0.983
	0.	36.80	-0.066	-0.663
	5.	25.33	-0.006	-0.055
	10.	18.58	0.003	0.030
60.	-5.	25.10	-0.094	-0.936
	0.	32.12	-0.075	-0.752
	5.	24.89	-0.009	-0.093
	10.	18.76	0.003	0.031
120.	-5.	33.24	-0.090	-0.895
	0.	35.51	-0.070	-0.703
	5.	26.34	-0.006	-0.064
	10.	19.49	0.005	0.047
180.	-5.	49.96	-0.081	-0.806
	0.	41.51	-0.059	-0.588
	5.	28.25	-0.001	-0.012
	10.	20.23	0.007	0.068
240.	-5.	33.02	-0.092	-0.919
	0.	35.76	-0.070	-0.702
	5.	26.47	-0.006	-0.061
	10.	19.54	0.005	0.048
300.	-5.	25.11	-0.094	-0.936
	0.	32.12	-0.075	-0.752
	5.	24.89	-0.009	-0.094
	10.	18.76	0.003	0.031

```
************************************
*      GPS TEST    FAST TRACE      *
*   CHING-CHIU IONOSPHERIC MODEL   *
************************************
```

SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 09/21/87 1800 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	18.45	-0.030	-0.305
	0.	14.98	-0.013	-0.128
	5.	9.65	-0.006	-0.058
	10.	7.16	-0.002	-0.019
60.	-5.	5.90	-0.018	-0.180
	0.	8.03	-0.024	-0.238
	5.	7.08	-0.009	-0.095
	10.	5.69	-0.004	-0.037
120.	-5.	9.64	-0.014	-0.140
	0.	9.16	-0.022	-0.219
	5.	7.45	-0.009	-0.087
	10.	5.84	-0.003	-0.034
180.	-5.	32.53	-0.008	-0.076
	0.	19.37	-0.012	-0.125
	5.	11.59	-0.002	-0.021
	10.	7.86	0.000	0.000
240.	-5.	24.38	-0.025	-0.246
	0.	19.37	-0.023	-0.228
	5.	13.47	-0.003	-0.033
	10.	9.58	0.001	0.014
300.	-5.	16.55	-0.034	-0.339
	0.	17.20	-0.027	-0.271
	5.	12.84	-0.005	-0.048
	10.	9.35	0.001	0.008

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*************************************
*      GPS TEST    FAST TRACE       *
*  CHING-CHIU IONOSPHERIC MODEL     *
*************************************
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 12/21/87 0000 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	19.60	-0.011	-0.115
	0.	10.12	0.012	0.119
	5.	4.02	0.001	0.009
	10.	2.58	-0.001	-0.008
60.	-5.	3.40	-0.006	-0.064
	0.	3.90	-0.009	-0.087
	5.	3.25	-0.004	-0.036
	10.	2.51	-0.001	-0.013
120.	-5.	4.14	-0.006	-0.057
	0.	4.16	-0.008	-0.083
	5.	3.35	-0.003	-0.034
	10.	2.55	-0.001	-0.012
180.	-5.	7.84	-0.003	-0.033
	0.	5.66	-0.006	-0.063
	5.	3.88	-0.002	-0.024
	10.	2.74	-0.001	-0.008
240.	-5.	5.12	-0.004	-0.045
	0.	4.43	-0.008	-0.078
	5.	3.42	-0.003	-0.033
	10.	2.58	-0.001	-0.012
300.	-5.	3.40	-0.006	-0.064
	0.	3.90	-0.009	-0.087
	5.	3.25	-0.004	-0.036
	10.	2.51	-0.001	-0.013

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*************************************
*       GPS TEST     FAST TRACE     *
*   CHING-CHIU IONOSPHERIC MODEL    *
*************************************
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 12/21/87 0600 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	16.37	-0.018	-0.179
	0.	13.21	-0.004	-0.036
	5.	6.74	0.000	0.004
	10.	4.34	-0.001	-0.011
60.	-5.	7.62	-0.012	-0.121
	0.	7.71	-0.014	-0.144
	5.	6.04	-0.005	-0.049
	10.	4.53	-0.001	-0.013
120.	-5.	11.34	-0.007	-0.068
	0.	8.79	-0.013	-0.125
	5.	6.44	-0.004	-0.041
	10.	4.71	-0.001	-0.010
180.	-5.	9.54	-0.010	-0.098
	0.	8.26	-0.013	-0.131
	5.	6.17	-0.004	-0.045
	10.	4.55	-0.001	-0.013
240.	-5.	5.81	-0.011	-0.108
	0.	6.43	-0.015	-0.148
	5.	5.34	-0.006	-0.058
	10.	4.14	-0.002	-0.021
300.	-5.	4.49	-0.011	-0.113
	0.	5.81	-0.015	-0.153
	5.	5.05	-0.006	-0.063
	10.	3.99	-0.002	-0.023

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***********************************
*     GPS TEST    FAST TRACE      *
*  CHING-CHIU IONOSPHERIC MODEL   *
***********************************
```

SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 12/21/87 1200 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	23.84	-0.076	-0.764
	0.	28.95	-0.059	-0.593
	5.	20.99	-0.009	-0.094
	10.	15.71	0.000	0.000
60.	-5.	20.45	-0.074	-0.740
	0.	26.60	-0.064	-0.645
	5.	21.08	-0.011	-0.112
	10.	16.03	0.000	0.005
120.	-5.	31.80	-0.068	-0.679
	0.	31.29	-0.058	-0.578
	5.	23.09	-0.007	-0.072
	10.	17.05	0.003	0.027
180.	-5.	54.18	-0.055	-0.553
	0.	39.21	-0.043	-0.425
	5.	25.60	0.000	-0.004
	10.	18.02	0.005	0.055
240.	-5.	30.51	-0.072	-0.723
	0.	31.36	-0.058	-0.584
	5.	23.18	-0.007	-0.071
	10.	17.09	0.003	0.028
300.	-5.	20.45	-0.074	-0.740
	0.	26.60	-0.064	-0.645
	5.	21.08	-0.011	-0.112
	10.	16.04	0.000	0.004

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*************************************
*       GPS TEST     FAST TRACE     *
*   CHING-CHIU IONOSPHERIC MODEL    *
*************************************
```

SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 12/21/87 1800 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	14.13	-0.018	-0.184
	0.	9.92	-0.002	-0.021
	5.	5.72	-0.004	-0.037
	10.	4.21	-0.002	-0.018
60.	-5.	4.49	-0.011	-0.113
	0.	5.81	-0.015	-0.153
	5.	5.05	-0.006	-0.063
	10.	3.99	-0.002	-0.023
120.	-5.	7.37	-0.009	-0.087
	0.	6.80	-0.014	-0.140
	5.	5.43	-0.006	-0.056
	10.	4.17	-0.002	-0.020
180.	-5.	27.14	0.005	0.049
	0.	13.71	-0.003	-0.027
	5.	7.52	0.000	-0.005
	10.	4.92	0.000	0.000
240.	-5.	18.25	0.003	0.026
	0.	10.44	-0.009	-0.087
	5.	6.84	-0.003	-0.029
	10.	4.84	-0.001	-0.006
300.	-5.	7.62	-0.012	-0.121
	0.	7.71	-0.014	-0.144
	5.	6.05	-0.005	-0.049
	10.	4.54	-0.001	-0.013

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 12/21/87 1800 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	16.9	22.6	
-25.	47.0	63.0	
-20.	4.4	5.9	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	0.9	1.3	
-25.	0.2	0.3	
-20.	0.0	0.0	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	101.0	135.4	
-25.	110.2	147.7	
-20.	4.8	6.4	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	139.3	186.7	
-25.	462.8	620.1	
-20.	36.3	48.6	
-15.	0.6	0.8	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	339.0	454.2	
-25.	502.0	672.7	
-20.	14.6	19.5	
-15.	0.2	0.2	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	15.0	20.2	
-25.	2.7	3.6	
-20.	0.0	0.1	
-15.	0.0	0.0	

APPENDIX B

- PART 2 -

ALTITUDE:	100 km
SUNSPOT NUMBER:	200
LATITUDE:	40°N
LONGITUDE:	270°E
FREQUENCY:	1 GHz

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 03/21/87 0000 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	16.6	22.2	
0.	15.4	20.7	
5.	7.3	9.8	
10.	1.9	2.5	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	0.4	0.6	
0.	0.5	0.7	
5.	0.3	0.4	
10.	0.2	0.3	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	7.6	10.2	
0.	4.3	5.8	
5.	2.2	3.0	
10.	1.2	1.6	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	28.1	37.6	
0.	17.0	22.7	
5.	8.9	11.9	
10.	4.5	6.1	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	19.9	26.7	
0.	9.2	12.3	
5.	4.1	5.5	
10.	2.0	2.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	0.4	0.6	
0.	0.5	0.7	
5.	0.3	0.4	
10.	0.2	0.3	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 03/21/87 0600 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	19.4	26.0	
0.	20.3	27.2	
5.	12.5	16.8	
10.	5.2	6.9	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	11.1	14.9	
0.	9.9	13.3	
5.	6.0	8.1	
10.	3.9	5.2	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	22.9	30.7	
0.	15.0	20.1	
5.	8.3	11.1	
10.	5.0	6.8	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	25.8	34.6	
0.	17.2	23.1	
5.	9.6	12.8	
10.	5.6	7.4	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	9.4	12.6	
0.	6.5	8.7	
5.	3.8	5.1	
10.	2.4	3.2	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	1.1	1.5	
0.	2.1	2.8	
5.	1.6	2.1	
10.	1.2	1.6	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 03/21/87 1200 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	38.3	51.3	
0.	50.1	67.1	
5.	37.3	49.9	
10.	24.4	32.7	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	28.4	38.1	
0.	38.5	51.6	
5.	30.1	40.3	
10.	22.9	30.6	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	91.4	122.5	
0.	66.4	89.0	
5.	42.4	56.8	
10.	28.9	38.7	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	181.2	242.8	
0.	121.1	162.2	
5.	68.1	91.2	
10.	40.5	54.3	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	77.9	104.4	
0.	65.0	87.1	
5.	43.0	57.7	
10.	29.5	39.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	28.4	38.1	
0.	38.5	51.6	
5.	30.1	40.3	
10.	22.9	30.7	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 03/21/87 1800 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	17.8	23.8	
0.	18.8	25.1	
5.	9.7	13.1	
10.	3.7	4.9	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	1.1	1.5	
0.	2.1	2.8	
5.	1.6	2.1	
10.	1.2	1.6	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	33.0	44.2	
0.	16.0	21.5	
5.	7.4	10.0	
10.	3.9	5.2	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	147.8	198.1	
0.	81.3	108.9	
5.	37.4	50.1	
10.	17.0	22.7	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	81.4	109.1	
0.	39.2	52.5	
5.	17.5	23.5	
10.	8.8	11.8	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	11.1	14.9	
0.	10.0	13.4	
5.	6.0	8.1	
10.	3.9	5.3	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 06/21/87 0000 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	11.7	15.7	
0.	11.1	14.9	
5.	5.9	7.9	
10.	1.9	2.5	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	0.9	1.2	
0.	1.0	1.4	
5.	0.6	0.8	
10.	0.4	0.6	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	14.1	18.9	
0.	8.9	12.0	
5.	5.1	6.8	
10.	2.9	3.9	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	48.1	64.4	
0.	33.0	44.2	
5.	19.4	26.0	
10.	10.8	14.4	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	42.1	56.4	
0.	21.9	29.4	
5.	10.7	14.3	
10.	5.4	7.3	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	0.9	1.2	
0.	1.1	1.4	
5.	0.6	0.9	
10.	0.5	0.6	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 06/21/87 0600 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	30.0	40.3	
0.	32.4	43.4	
5.	22.0	29.5	
10.	12.2	16.4	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	20.4	27.3	
0.	20.7	27.8	
5.	13.9	18.7	
10.	9.7	13.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	29.1	39.0	
0.	24.2	32.4	
5.	15.5	20.8	
10.	10.5	14.1	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	31.4	42.1	
0.	27.0	36.2	
5.	17.6	23.6	
10.	11.6	15.6	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	14.6	19.5	
0.	16.1	21.6	
5.	11.6	15.6	
10.	8.5	11.3	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	7.1	9.5	
0.	12.1	16.2	
5.	9.5	12.7	
10.	7.3	9.8	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 06/21/87 1200 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	55.6	74.5	
0.	68.6	92.0	
5.	51.5	69.0	
10.	33.4	44.8	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	38.4	51.5	
0.	50.1	67.2	
5.	39.2	52.5	
10.	29.7	39.8	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	82.9	111.1	
0.	69.7	93.4	
5.	47.8	64.0	
10.	33.9	45.4	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	154.7	207.3	
0.	112.7	151.0	
5.	68.3	91.5	
10.	43.2	57.9	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	76.7	102.7	
0.	70.2	94.0	
5.	48.9	65.5	
10.	34.6	46.4	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	38.4	51.5	
0.	50.1	67.2	
5.	39.2	52.6	
10.	29.7	39.8	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 06/21/87 1800 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	28.3	38.0	
0.	30.9	41.4	
5.	19.4	26.0	
10.	10.5	14.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	7.1	9.5	
0.	12.1	16.2	
5.	9.5	12.7	
10.	7.3	9.8	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	51.7	69.3	
0.	31.9	42.8	
5.	17.8	23.9	
10.	11.0	14.8	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	150.0	201.0	
0.	94.8	127.0	
5.	49.8	66.7	
10.	25.8	34.6	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	76.2	102.1	
0.	45.7	61.2	
5.	24.5	32.9	
10.	14.4	19.3	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	20.4	27.3	
0.	20.7	27.8	
5.	14.0	18.7	
10.	9.7	13.1	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 09/21/87 0000 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	16.7	22.3	
0.	15.5	20.7	
5.	7.3	9.8	
10.	1.9	2.5	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	0.4	0.6	
0.	0.5	0.7	
5.	0.3	0.4	
10.	0.2	0.3	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	7.1	9.5	
0.	4.1	5.4	
5.	2.1	2.8	
10.	1.2	1.5	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	25.7	34.5	
0.	15.6	20.9	
5.	8.2	11.0	
10.	4.2	5.6	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	18.7	25.1	
0.	8.8	11.7	
5.	3.9	5.3	
10.	1.9	2.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	0.4	0.6	
0.	0.6	0.7	
5.	0.3	0.4	
10.	0.2	0.3	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 09/21/87 0600 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	18.8	25.2	
0.	19.5	26.1	
5.	11.9	16.0	
10.	4.8	6.4	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	11.0	14.8	
0.	9.8	13.2	
5.	5.9	7.9	
10.	3.8	5.1	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	22.0	29.5	
0.	14.6	19.5	
5.	8.1	10.8	
10.	4.9	6.6	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	23.4	31.4	
0.	15.6	20.8	
5.	8.6	11.5	
10.	5.0	6.6	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	8.7	11.6	
0.	6.2	8.2	
5.	3.6	4.9	
10.	2.3	3.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	1.1	1.5	
0.	2.1	2.8	
5.	1.5	2.0	
10.	1.2	1.6	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 09/21/87 1200 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	38.1	51.1	
0.	49.8	66.8	
5.	37.1	49.7	
10.	24.3	32.5	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	28.3	37.9	
0.	38.4	51.4	
5.	30.0	40.1	
10.	22.8	30.5	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	87.8	117.7	
0.	65.1	87.2	
5.	41.8	56.0	
10.	28.6	38.3	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	169.5	227.1	
0.	115.5	154.7	
5.	65.7	88.1	
10.	39.5	52.9	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	74.7	100.1	
0.	63.4	85.0	
5.	42.3	56.7	
10.	29.2	39.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	28.3	37.9	
0.	38.4	51.4	
5.	30.0	40.2	
10.	22.8	30.5	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 09/21/87 1800 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	17.1	22.9	
0.	18.0	24.1	
5.	9.2	12.3	
10.	3.2	4.4	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	1.1	1.5	
0.	2.1	2.8	
5.	1.5	2.1	
10.	1.2	1.6	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	30.6	41.1	
0.	15.1	20.2	
5.	7.0	9.4	
10.	3.7	5.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	1[illegible]4.7	180.5	
0.	74.4	99.7	
5.	34.4	46.1	
10.	15.6	20.9	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	75.9	101.7	
0.	37.0	49.5	
5.	16.7	22.3	
10.	8.4	11.3	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	11.0	14.8	
0.	9.8	13.2	
5.	5.9	8.0	
10.	3.9	5.2	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 12/21/87 0000 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	24.4	32.8	
0.	21.6	28.9	
5.	8.6	11.6	
10.	1.8	2.4	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	0.3	0.4	
0.	0.4	0.5	
5.	0.2	0.3	
10.	0.2	0.2	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	3.7	5.0	
0.	2.0	2.6	
5.	0.9	1.3	
10.	0.5	0.7	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	15.9	21.3	
0.	8.3	11.1	
5.	3.8	5.1	
10.	1.8	2.4	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	8.5	11.4	
0.	3.6	4.8	
5.	1.5	2.0	
10.	0.7	0.9	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	0.3	0.4	
0.	0.4	0.5	
5.	0.2	0.3	
10.	0.2	0.2	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 12/21/87 0600 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	16.8	22.5	
0.	16.7	22.4	
5.	9.1	12.2	
10.	2.7	3.6	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	1.6	2.2	
0.	1.5	2.0	
5.	0.9	1.2	
10.	0.6	0.8	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	11.5	15.4	
0.	5.0	6.7	
5.	2.3	3.1	
10.	1.3	1.7	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	16.0	21.4	
0.	9.0	12.0	
5.	4.4	5.9	
10.	2.3	3.1	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	5.3	7.1	
0.	3.4	4.5	
5.	1.8	2.4	
10.	1.1	1.5	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	0.6	0.8	
0.	1.0	1.3	
5.	0.7	0.9	
10	0.5	0.6	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 12/21/87 1200 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	21.2	28.4	
0.	29.7	39.9	
5.	21.4	28.6	
10.	13.7	18.4	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	15.9	21.3	
0.	23.0	30.8	
5.	17.7	23.7	
10.	13.5	18.1	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	95.2	127.6	
0.	57.3	76.7	
5.	32.5	43.6	
10.	20.7	27.8	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	207.2	277.7	
0.	123.6	165.7	
5.	62.3	83.5	
10.	33.7	45.2	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	70.3	94.2	
0.	52.1	69.8	
5.	32.0	42.9	
10.	20.9	28.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	15.8	21.2	
0.	23.0	30.8	
5.	17.7	23.7	
10.	13.5	18.1	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 12/21/87 1800 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	15.2	20.3	
0.	15.1	20.3	
5.	6.2	8.3	
10.	1.4	1.9	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	0.6	0.8	
0.	1.0	1.3	
5.	0.7	0.9	
10.	0.5	0.6	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	15.3	20.4	
0.	7.0	9.4	
5.	3.2	4.2	
10.	1.6	2.2	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	98.8	132.4	
0.	48.4	64.9	
5.	19.9	26.6	
10.	8.1	10.9	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	62.0	83.1	
0.	23.2	31.1	
5.	8.5	11.3	
10.	3.6	4.8	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	1.7	2.2	
0.	1.5	2.1	
5.	0.9	1.2	
10.	0.6	0.8	

APPENDIX B

- PART 3 -

ALTITUDE:	1000 km
SUNSPOT NUMBER:	0
LATITUDE:	40°N
LONGITUDE:	270°E
FREQUENCY:	1 GHz

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 03/21/87 0000 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	20.6	27.6	
-25.	7.3	9.8	
-20.	0.1	0.1	
-15	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	5.6	7.5	
-25.	1.8	2.4	
-20.	0.0	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	11.4	15.3	
-25.	5.5	7.4	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	21.5	28.8	
-25.	16.2	21.7	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	37.6	50.4	
-25.	17.0	22.8	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	5.6	7.5	
-25.	1.6	2.4	
-20.	0.0	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 03/21/87 0600 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	25.2	33.7	
-25.	14.8	19.8	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	23.3	31.2	
-25.	6.9	9.2	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	4[illegible]	65.7	
-25.	1[illegible]	13.4	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	27.8	37.2	
-25.	8.8	11.8	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	13.5	18.1	
-25.	4.8	6.5	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	5.9	7.9	
-25.	2.1	2.8	
-20.	0.1	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 03/21/87 1200 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	29.5	39.6	
-25.	22.3	29.8	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	24.7	33.1	
-25.	7.9	10.6	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	108.6	145.5	
-25.	28.8	38.6	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	109.4	146.6	
-25.	60.1	80.5	
-20.	0.4	0.5	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	70.4	94.4	
-25.	18.1	24.3	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	24.5	32.8	
-25.	7.9	10.6	
-20.	0.2	0.3	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 03/21/87 1800 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	21.0	28.1	
-25.	12.9	17.3	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	6.0	8.0	
-25.	2.1	2.8	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	43.5	58.3	
-25.	24.4	32.7	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	90.3	121.0	
-25.	103.3	138.4	
-20.	0.5	0.6	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	106.6	142.9	
-25.	46.6	62.5	
-20.	0.3	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	23.2	31.1	
-25.	6.9	9.2	
-20.	0.2	0.2	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 06/21/87 0000 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	24.7	33.1	
-25.	7.6	10.2	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	8.9	12.0	
-25.	2.6	3.4	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	12.9	17.3	
-25.	7.2	9.6	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	23.0	30.8	
-25.	20.4	27.4	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	42.8	57.3	
-25.	24.7	33.1	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	9.0	12.0	
-25.	2.6	3.4	
-20.	0.1	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 06/21/87 0600 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	35.0	46.9	
-25.	17.7	23.7	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	27.1	36.3	
-25.	8.0	10.7	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	49.0	65.7	
-25.	10.6	14.3	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	27.5	36.9	
-25.	10.0	13.4	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	15.7	21.0	
-25.	5.7	7.6	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	11.2	15.0	
-25.	3.6	4.8	
-20.	0.1	0.2	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 06/21/87 1200 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	37.9	50.8	
-25.	30.2	40.5	
-20.	0.4	0.5	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	28.2	37.8	
-25.	8.8	11.7	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	96.3	129.1	
-25.	25.5	34.1	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	100.9	135.3	
-25.	54.2	72.7	
-20.	0.4	0.5	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	67.7	90.7	
-25.	17.8	23.8	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	28.0	37.5	
-25.	8.8	11.7	
-20.	0.2	0.3	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 06/21/87 1800 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	30.8	41.3	
-25.	15.7	21.1	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	11.4	15.2	
-25.	3.6	4.8	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	50.4	67.5	
-25.	31.1	41.7	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	81.3	108.9	
-25.	101.7	136.3	
-20.	0.5	0.7	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	94.7	126.8	
-25.	41.8	56.1	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	27.1	36.3	
-25.	8.0	10.7	
-20.	0.2	0.3	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 09/21/87 0000 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	20.6	27.6	
-25.	7.3	9.8	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	5.6	7.5	
-25.	1.8	2.4	
-20.	0.0	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	10.2	13.6	
-25.	4.8	6.5	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	18.4	24.7	
-25.	13.7	18.4	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	31.5	42.2	
-25.	14.4	19.2	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	5.6	7.5	
-25.	1.8	2.4	
-20.	0.0	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 09/21/87 0600 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	24.2	32.4	
-25.	14.5	19.4	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	23.2	31.0	
-25.	6.9	9.2	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	44.0	58.9	
-25.	9.4	12.6	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	24.4	32.7	
-25.	7.7	10.4	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	12.0	16.1	
-25.	4.3	5.8	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	5.9	7.9	
-25.	2.1	2.8	
-20.	0.1	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 09/21/87 1200 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	29.4	39.4	
-25.	22.2	29.7	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	24.6	33.0	
-25.	7.9	10.6	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	93.5	125.3	
-25.	25.2	33.8	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	94.2	126.2	
-25.	50.4	67.5	
-20.	0.3	0.5	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	62.6	83.8	
-25.	16.4	22.0	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	24.4	32.7	
-25.	7.9	10.6	
-20.	0.2	0.3	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 09/21/87 1800 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	20.0	26.8	
-25.	12.6	16.9	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	6.0	8.0	
-25.	2.1	2.8	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	36.5	48.9	
-25.	20.4	27.3	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	74.6	99.9	
-25.	84.3	112.9	
-20.	0.4	0.5	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	90.2	120.9	
-25.	39.0	52.2	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	23.1	31.0	
-25.	6.9	9.2	
-20.	0.2	0.2	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 12/21/87 0000 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	24.6	32.9	
-25.	9.3	12.5	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	4.5	6.0	
-25.	1.5	2.0	
-20.	0.0	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	10.1	13.5	
-25.	4.2	5.6	
-20.	0.0	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	20.1	26.9	
-25.	12.5	16.7	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	30.8	41.1	
-25.	10.9	14.7	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	4.5	6.0	
-25.	1.5	2.0	
-20.	0.0	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 12/21/87 0600 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	19.1	25.6	
-25.	12.9	17.3	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	15.3	20.5	
-25.	4.6	6.1	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	42.6	57.1	
-25.	8.1	10.8	
-20.	0.1	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	25.2	33.7	
-25.	6.7	8.9	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	11.7	15.7	
-25.	3.8	5.1	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	4.7	6.3	
-25.	1.6	2.2	
-20.	0.0	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 12/21/87 1200 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	19.0	25.5	
-25.	14.6	19.6	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	18.0	24.1	
-25.	6.4	8.6	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	112.5	150.7	
-25.	30.7	41.1	
-20.	0.3	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	114.8	153.9	
-25.	64.9	87.0	
-20.	0.3	0.5	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	66.7	89.4	
-25.	17.0	22.7	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	17.8	23.9	
-25.	6.4	8.6	
-20.	0.2	0.2	
-15.	0.0	0.0	

APPENDIX B

- PART 4 -

ALTITUDE:	1000 km
SUNSPOT NUMBER:	200
LATITUDE:	40°N
LONGITUDE:	270°E
FREQUENCY.	1 GHz

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 03/21/87 0000 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	23.1	30.9	
-25.	69.6	93.3	
-20.	3.8	5.1	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	1.6	2.2	
-25.	0.4	0.5	
-20.	0.0	0.0	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	25.6	34.3	
-25.	35.7	47.9	
-20.	4.1	5.5	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	121.7	163.1	
-25.	110.4	148.0	
-20.	14.5	19.5	
-15.	0.4	0.6	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	130.0	174.1	
-25.	123.5	165.5	
-20.	12.2	16.3	
-15.	0.3	0.4	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	2.3	3.0	
-25.	0.4	0.5	
-20.	0.0	0.0	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 12/21/87 1800 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	14.9	20.0	
-25.	11.0	14.7	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	4.7	6.3	
-25.	1.6	2.2	
-20.	0.0	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	33.9	45.4	
-25.	15.5	20.8	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	81.4	109.1	
-25.	82.2	110.1	
-20.	0.4	0.5	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	104.7	140.3	
-25.	42.5	57.0	
-20.	0.2	0.3	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	15.3	20.5	
-25.	4.6	6.1	
-20.	0.1	0.1	
-15.	0.0	0.0	

APPENDIX C
- PART 1 -

ALTITUDE:	100 km
SUNSPOT NUMBER:	0
LATITUDE:	40°N
LONGITUDE:	270°E
FREQUENCY:	1 GHz

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 03/21/87 0600 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	21.2	28.4	
-25.	60.1	80.5	
-20.	8.0	10.8	
-15.	0.3	0.4	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	30.6	41.0	
-25.	7.2	9.7	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	137.8	184.6	
-25.	113.3	151.8	
-20.	3.4	4.5	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	158.8	212.8	
-25.	127.2	170.5	
-20.	5.5	7.3	
-15.	0.1	0.2	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	26.4	35.4	
-25.	46.3	62.0	
-20.	3.0	[illegible]	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	1.5	2.1	
-25.	0.3	0.5	
-20.	0.0	0.0	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 03/21/87 1200 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	32.9	44.1	
-25.	45.4	60.8	
-20.	11.2	15.0	
-15.	0.4	0.5	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	35.1	47.0	
-25.	11.1	14.9	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	364.1	487.9	
-25.	456.8	612.1	
-20.	15.6	20.8	
-15.	0.2	0.3	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	189.3	253.6	
-25.	687.9	921.7	
-20.	41.4	55.5	
-15.	0.7	0.9	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	189.1	253.4	
-25.	293.7	393.6	
-20.	9.4	12.6	
-15.	0.2	0.2	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	32.1	43.0	
-25.	10.5	14.1	
-20.	0.3	0.5	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 03/21/87 1800 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	20.7	27.7	
-25.	45.6	61.1	
-20.	5.8	7.8	
-15.	0.1	0.2	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	2.3	3.1	
-25.	0.6	0.8	
-20.	0.0	0.0	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	144.0	193.0	
-25.	180.3	241.7	
-20.	17.7	23.7	
-15.	0.3	0.4	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	152.4	204.2	
-25.	537.1	719.7	
-20.	85.6	114.7	
-15.	1.8	2.5	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	336.4	450.8	
-25.	453.5	607.7	
-20.	30.2	40.5	
-15.	0.5	0.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	30.5	40.8	
-25.	7.3	9.8	
-20.	0.2	0.2	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 06/21/87 0000 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	32.8	43.9	
-25.	45.7	61.3	
-20.	3.5	4.7	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	3.7	4.9	
-25.	0.7	1.0	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	28.8	38.6	
-25.	48.4	64.8	
-20.	12.8	17.2	
-15.	0.5	0.6	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	114.2	153.0	
-25.	139.4	186.8	
-20.	41.0	54.9	
-15.	1.6	2.1	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	145.1	194.4	
-25.	187.4	251.1	
-20.	41.0	54.9	
-15.	1.2	1.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	5.1	6.8	
-25.	0.9	1.2	
-20.	0.1	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 06/21/87 0600 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	38.4	51.5	
-25.	59.7	80.1	
-20.	10.6	14.2	
-15.	0.4	0.6	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	44.4	59.5	
-25.	11.7	15.7	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	125.0	167.5	
-25.	93.5	125.3	
-20.	5.8	7.7	
-15.	0.2	0.2	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	96.5	129.3	
-25.	98.5	131.9	
-20.	9.4	12.6	
-15.	0.3	0.4	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	27.3	36.6	
-25.	45.3	60.7	
-20.	6.4	8.6	
-15.	0.2	0.3	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	6.5	8.8	
-25.	1.3	1.7	
-20.	0.1	0.1	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 06/21/87 1200 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	50.1	67.1	
-25.	64.3	86.2	
-20.	20.3	27.2	
-15.	0.7	1.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	49.5	66.3	
-25.	15.7	21.1	
-20.	0.5	0.6	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	295.7	396.3	
-25.	294.7	394.9	
-20.	19.5	26.1	
-15.	0.4	0.5	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	155.5	208.3	
-25.	470.8	630.9	
-20.	52.5	70.3	
-15.	1.1	1.4	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	169.3	226.9	
-25.	207.6	278.2	
-20.	13.5	18.1	
-15.	0.3	0.4	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	46.9	62.9	
-25.	15.4	20.6	
-20.	0.5	0.7	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 06/21/87 1800 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	38.1	51.0	
-25.	48.1	64.5	
-20.	7.6	10.2	
-15.	0.2	0.3	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	8.8	11.7	
-25.	2.0	2.7	
-20.	0.1	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	164.5	220.5	
-25.	223.0	298.8	
-20.	41.6	55.7	
-15.	1.0	1.3	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	116.0	155.4	
-25.	430.3	576.6	
-20.	126.9	170.0	
-15.	3.6	4.8	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	272.1	364.6	
-25.	318.1	426.3	
-20.	41.2	55.1	
-15.	0.9	1.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	43.9	58.8	
-25.	11.6	15.6	
-20.	0.3	0.4	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 09/21/87 0000 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	23.1	30.9	
-25.	70.0	93.7	
-20.	3.8	5.1	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	1.6	2.1	
-25.	0.3	0.5	
-20.	0.0	0.0	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	23.1	31.0	
-25.	32.9	44.0	
-20.	3.8	5.1	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	110.3	147.8	
-25.	100.6	134.8	
-20.	13.2	17.7	
-15.	0.4	0.5	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	117.0	156.8	
-25.	113.9	152.6	
-20.	11.6	15.5	
-15.	0.3	0.3	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	2.2	2.9	
-25.	0.4	0.5	
-20.	0.0	0.0	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 09/21/87 0600 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	20.2	27.1	
-25.	59.8	80.2	
-20.	8.0	10.7	
-15.	0.3	0.4	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	30.3	40.6	
-25.	7.1	9.6	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	126.7	169.8	
-25.	105.0	140.7	
-20.	3.1	4.2	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	144.6	193.7	
-25.	115.7	155.0	
-20.	5.0	6.7	
-15.	0.1	0.2	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	23.8	31.9	
-25.	42.4	56.8	
-20.	2.7	3.7	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	1.5	2.0	
-25.	0.3	0.4	
-20.	0.0	0.0	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 09/21/87 1200 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	32.7	43.8	
-25.	45.2	60.5	
-20.	11.1	14.9	
-15.	0.4	0.5	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	34.7	46.5	
-25.	11.0	14.8	
-20.	0.3	0.4	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	333.2	446.4	
-25.	423.1	566.9	
-20.	14.5	19.4	
-15.	0.2	0.3	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	177.2	237.5	
-25.	627.5	840.8	
-20.	37.8	50.7	
-15.	0.6	0.9	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	175.1	234.6	
-25.	270.8	362.9	
-20.	8.6	11.6	
-15.	0.2	0.2	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	31.9	42.7	
-25.	10.4	14.0	
-20.	0.3	0.5	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 09/21/87 1800 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	19.6	26.3	
-25.	45.3	60.8	
-20.	5.8	7.8	
-15.	0.1	0.2	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	2.2	3.0	
-25.	0.6	0.8	
-20.	0.0	0.0	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	129.8	173.9	
-25.	165.3	221.5	
-20.	16.4	21.9	
-15.	0.3	0.4	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	136.9	183.5	
-25.	485.9	651.1	
-20.	77.9	104.3	
-15.	1.7	2.3	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	304.3	407.7	
-25.	414.6	555.6	
-20.	27.7	37.1	
-15.	0.4	0.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	30.1	40.3	
-25.	7.2	9.6	
-20.	0.2	0.2	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 12/21/87 0000 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	27.5	36.9	
-25.	104.4	139.9	
-20.	4.0	5.4	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	0.9	1.2	
-25.	0.2	0.2	
-20.	0.0	0.0	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	19.5	26.2	
-25.	24.1	32.3	
-20.	1.1	1.5	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	130.7	175.1	
-25.	87.9	117.8	
-20.	4.8	6.4	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	100.4	134.5	
-25.	73.6	98.6	
-20.	3.1	4.2	
-15.	0.0	0.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	1.0	1.4	
-25.	0.1	0.2	
-20.	0.0	0.0	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00   LON 270.00   ALT 1000. KM
DATE AND TIME 12/21/87 0600 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	17.7	23.8	
-25.	63.9	85.7	
-20.	6.0	8.1	
-15.	0.2	0.2	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	14.4	19.2	
-25.	2.5	3.3	
-20.	0.0	0.1	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	123.0	164.8	
-25.	91.6	122.8	
-20.	1.2	1.6	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	180.3	241.6	
-25.	99.9	133.8	
-20.	2.0	2.7	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	21.2	28.4	
-25.	33.4	44.8	
-20.	0.9	1.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	0.8	1.0	
-25.	0.2	0.2	
-20.	0.0	0.0	
-15.	0.0	0.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 1000. KM
DATE AND TIME 12/21/87 1200 HRS
SUNSPOT NUMBER IS 200.

HORZ ANG	TEC	NSEC	AZIM = 0.
-30.	18.0	24.2	
-25.	28.8	38.6	
-20.	5.8	7.8	
-15.	0.2	0.2	

HORZ ANG	TEC	NSEC	AZIM = 60.
-30.	17.3	23.2	
-25.	5.9	7.9	
-20.	0.2	0.2	
-15.	0.0	0.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-30.	383.8	514.3	
-25.	642.9	861.4	
-20.	10.5	14.0	
-15.	0.1	0.2	

HORZ ANG	TEC	NSEC	AZIM = 180.
-30.	228.3	306.0	
-25.	1009.3	1352.5	
-20.	29.8	40.0	
-15.	0.4	0.5	

HORZ ANG	TEC	NSEC	AZIM = 240.
-30.	180.1	241.3	
-25.	337.1	451.7	
-20.	5.2	7.0	
-15.	0.1	0.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-30.	14.7	19.7	
-25.	5.0	6.7	
-20.	0.2	0.2	
-15.	0.0	0.0	

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*************************************
*      GPS TEST     FAST TRACE      *
*   CHING-CHIU IONOSPHERIC MODEL    *
*************************************
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 03/21/87 0000 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	15.56	-0.012	-0.119
	0.	9.24	0.004	0.043
	5.	4.50	-0.001	-0.007
	10.	3.06	-0.001	-0.010
60.	-5.	4.14	-0.008	-0.078
	0.	4.69	-0.010	-0.102
	5.	3.87	-0.004	-0.040
	10.	2.97	-0.001	-0.014
120.	-5.	5.02	-0.007	-0.066
	0.	4.94	-0.010	-0.097
	5.	3.94	-0.004	-0.039
	10.	2.99	-0.001	-0.014
180.	-5.	10.09	-0.004	-0.039
	0.	7.12	-0.007	-0.069
	5.	4.73	-0.002	-0.024
	10.	3.28	-0.001	-0.007
240.	-5.	6.96	-0.004	-0.044
	0.	5.50	-0.009	-0.086
	5.	4.10	-0.004	-0.035
	10.	3.04	-0.001	-0.012
300.	-5.	4.12	-0.008	-0.078
	0.	4.68	-0.010	-0.102
	5.	3.86	-0.004	-0.040
	10.	2.96	-0.001	-0.014

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*************************************
*      GPS TEST    FAST TRACE       *
*  CHING-CHIU IONOSPHERIC MODEL     *
*************************************
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 03/21/87 0600 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	21.53	-0.033	-0.325
	0.	19.26	-0.016	-0.163
	5.	11.43	-0.002	-0.020
	10.	7.84	-0.001	-0.011
60.	-5.	16.61	-0.034	-0.343
	0.	17.29	-0.028	-0.275
	5.	12.91	-0.005	-0.050
	10.	9.41	0.001	0.007
120.	-5.	18.15	-0.033	-0.325
	0.	17.80	-0.027	-0.268
	5.	13.12	-0.005	-0.046
	10.	9.50	0.001	0.009
180.	-5.	14.73	-0.023	-0.232
	0.	14.08	-0.025	-0.255
	5.	10.67	-0.007	-0.071
	10.	7.94	-0.001	-0.015
240.	-5.	7.41	-0.017	-0.172
	0.	8.67	-0.023	-0.234
	5.	7.37	-0.009	-0.093
	10.	5.84	-0.004	-0.037
300.	-5.	5.93	-0.018	-0.183
	0.	8.08	-0.024	-0.242
	5.	7.13	-0.010	-0.097
	10.	5.73	-0.004	-0.039

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**************************************
*      GPS TEST    FAST TRACE        *
*   CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 03/21/87 1200 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	32.22	-0.098	-0.985
	0.	36.88	-0.066	-0.664
	5.	25.37	-0.005	-0.055
	10.	18.60	0.003	0.030
60.	-5.	25.14	-0.094	-0.938
	0.	32.16	-0.075	-0.753
	5.	24.92	-0.009	-0.093
	10.	18.78	0.003	0.031
120.	-5.	34.46	-0.088	-0.881
	0.	35.89	-0.070	-0.697
	5.	26.49	-0.006	-0.061
	10.	19.57	0.005	0.048
180.	-5.	54.85	-0.077	-0.765
	0.	43.11	-0.056	-0.558
	5.	28.75	0.000	0.001
	10.	20.43	0.007	0.073
240.	-5.	34.26	-0.091	-0.909
	0.	36.23	-0.070	-0.697
	5.	26.66	-0.006	-0.058
	10.	19.64	0.005	0.050
300.	-5.	25.14	-0.094	-0.938
	0.	32.17	-0.075	-0.753
	5.	24.92	-0.009	-0.093
	10.	18.79	0.003	0.031

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*************************************
*      GPS TEST     FAST TRACE      *
*  CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270.   100. KM ALT
DATE-TIME: 03/21/87   1800 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	19.29	-0.033	-0.331
	0.	15.98	-0.015	-0.148
	5.	10.40	-0.006	-0.061
	10.	7.71	-0.002	-0.018
60.	-5.	5.93	-0.018	-0.183
	0.	8.08	-0.024	-0.242
	5.	7.13	-0.010	-0.097
	10.	5.74	-0.004	-0.039
120.	-5.	10.49	-0.013	-0.134
	0.	9.47	-0.022	-0.219
	5.	7.58	-0.009	-0.088
	10.	5.92	-0.004	-0.035
180.	-5.	38.45	-0.006	-0.061
	0.	22.02	-0.011	-0.114
	5.	12.77	-0.001	-0.012
	10.	8.54	0.001	0.005
240.	-5.	26.29	-0.023	-0.227
	0.	19.97	-0.022	-0.222
	5.	13.70	-0.003	-0.031
	10.	9.70	0.001	0.014
300.	-5.	16.61	-0.034	-0.344
	0.	17.29	-0.028	-0.276
	5.	12.92	-0.005	-0.050
	10.	9.42	0.001	0.007

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************************************
*      GPS TEST     FAST TRACE       *
*   CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 06/21/87 0600 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	29.80	-0.060	-0.599
	0.	28.80	-0.035	-0.348
	5.	18.44	-0.003	-0.026
	10.	12.98	0.001	0.009
60.	-5.	21.16	-0.056	-0.565
	0.	23.67	-0.045	-0.451
	5.	17.95	-0.007	-0.073
	10.	13.31	0.001	0.010
120.	-5.	21.64	-0.053	-0.533
	0.	23.41	-0.045	-0.449
	5.	17.74	-0.008	-0.077
	10.	13.17	0.001	0.007
180.	-5.	20.26	-0.048	-0.483
	0.	21.87	-0.046	-0.456
	5.	16.79	-0.009	-0.094
	10.	12.59	-0.001	-0.006
240.	-5.	12.07	-0.051	-0.510
	0.	18.22	-0.051	-0.506
	5.	15.24	-0.013	-0.125
	10.	11.85	-0.002	-0.023
300.	-5.	13.81	-0.051	-0.511
	0.	19.01	-0.049	-0.493
	5.	15.60	-0.012	-0.117
	10.	12.03	-0.002	-0.018

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*************************************
*      GPS TEST    FAST TRACE       *
*  CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 06/21/87 1200 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	39.00	-0.112	-1.121
	0.	42.45	-0.067	-0.668
	5.	27.84	-0.002	-0.018
	10.	20.08	0.005	0.051
60.	-5.	27.68	-0.104	-1.045
	0.	35.08	-0.080	-0.805
	5.	26.87	-0.008	-0.079
	10.	20.15	0.005	0.047
120.	-5.	34.69	-0.100	-0.996
	0.	37.79	-0.076	-0.764
	5.	27.99	-0.006	-0.056
	10.	20.71	0.006	0.059
180.	-5.	52.50	-0.088	-0.881
	0.	43.85	-0.064	-0.642
	5.	29.83	0.000	-0.005
	10.	21.39	0.008	0.080
240.	-5.	35.19	-0.101	-1.010
	0.	38.24	-0.076	-0.759
	5.	28.17	-0.005	-0.052
	10.	20.78	0.006	0.061
300.	-5.	27.69	-0.104	-1.045
	0.	35.09	-0.080	-0.805
	5.	26.87	-0.008	-0.079
	10.	20.16	0.005	0.047

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**************************************
*      GPS TEST    FAST TRACE        *
*   CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 06/21/87 0000 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 0.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	14.24	-0.014	-0.139
	0.	9.95	-0.004	-0.037
	5.	5.90	-0.002	-0.025
	10.	4.19	-0.001	-0.011
60.	-5.	5.84	-0.011	-0.113
	0.	6.52	-0.014	-0.137
	5.	5.30	-0.005	-0.050
	10.	4.04	-0.002	-0.016
120.	-5.	6.60	-0.009	-0.095
	0.	6.59	-0.013	-0.131
	5.	5.25	-0.005	-0.051
	10.	3.98	-0.002	-0.017
180.	-5.	13.31	-0.006	-0.063
	0.	9.61	-0.009	-0.095
	5.	6.37	-0.003	-0.030
	10.	4.40	-0.001	-0.008
240.	-5.	9.98	-0.006	-0.060
	0.	7.64	-0.011	-0.114
	5.	5.57	-0.004	-0.044
	10.	4.09	-0.001	-0.015
300.	-5.	5.84	-0.011	-0.113
	0.	6.52	-0.014	-0.137
	5.	5.30	-0.005	-0.050
	10.	4.04	-0.002	-0.016

APPENDIX C

- PART 2 -

ALTITUDE:	100 km
SUNSPOT NUMBER:	200
LATITUDE:	40°N
LONGITUDE:	270°E
FREQUENCY:	1 GHz

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************************************
*      GPS TEST    FAST TRACE      *
*   CHING-CHIU IONOSPHERIC MODEL   *
************************************
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 03/21/87 0000 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	22.22	-0.015	-0.150
	0.	20.67	0.001	0.015
	5.	9.77	0.019	0.186
	10.	2.51	0.008	0.085
60.	-5.	0.59	-0.004	-0.037
	0.	0.73	-0.001	-0.013
	5.	0.44	0.001	0.009
	10.	0.30	0.001	0.007
120.	-5.	10.24	0.000	-0.001
	0.	5.78	0.002	0.015
	5.	2.98	0.003	0.027
	10.	1.63	0.002	0.018
180.	-5.	37.64	0.003	0.030
	0.	22.72	0.009	0.091
	5.	11.90	0.010	0.098
	10.	6.06	0.006	0.064
240.	-5.	26.65	0.010	0.105
	0.	12.31	0.008	0.077
	5.	5.49	0.006	0.057
	10.	2.64	0.003	0.032
300.	-5.	0.58	-0.004	-0.036
	0.	0.73	-0.001	-0.013
	5.	0.44	0.001	0.009
	10.	0.31	0.001	0.007

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***********************************
*      GPS TEST     FAST TRACE      *
*   CHING-CHIU IONOSPHERIC MODEL    *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 03/21/87 0600 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	26.03	-0.035	-0.354
	0.	27.14	-0.015	-0.155
	5.	16.75	0.018	0.183
	10.	6.93	0.014	0.143
60.	-5.	14.89	-0.036	-0.364
	0.	13.31	-0.009	-0.092
	5.	8.05	0.009	0.094
	10.	5.22	0.008	0.080
120.	-5.	30.65	-0.026	-0.261
	0.	20.06	-0.003	-0.035
	5.	11.08	0.012	0.123
	10.	6.73	0.009	0.095
180.	-5.	34.56	-0.019	-0.192
	0.	23.07	-0.004	-0.040
	5.	12.83	0.010	0.104
	10.	7.42	0.008	0.081
240.	-5.	12.53	-0.012	-0.122
	0.	8.72	-0.008	-0.080
	5.	5.11	0.003	0.027
	10.	3.21	0.003	0.027
300.	-5.	1.50	-0.016	-0.158
	0.	2.79	-0.011	-0.114
	5.	2.08	0.000	0.004
	10.	1.61	0.001	0.014

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**************************************
*      GPS TEST    FAST TRACE        *
*  CHING-CHIU IONOSPHERIC MODEL      *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 03/21/87 1200 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	51.25	-0.167	-1.668
	0.	66.98	-0.133	-1.330
	5.	49.83	-0.002	-0.022
	10.	32.60	0.014	0.140
60.	-5.	37.99	-0.163	-1.627
	0.	51.52	-0.127	-1.274
	5.	40.21	-0.014	-0.140
	10.	30.54	0.006	0.061
120.	-5.	122.40	-0.125	-1.255
	0.	88.91	-0.096	-0.957
	5.	56.67	0.006	0.058
	10.	38.63	0.017	0.170
180.	-5.	242.66	-0.134	-1.336
	0.	162.15	-0.055	-0.547
	5.	91.13	0.044	0.442
	10.	54.22	0.039	0.393
240.	-5.	104.29	-0.151	-1.513
	0.	86.95	-0.105	-1.049
	5.	57.58	0.004	0.044
	10.	39.48	0.017	0.174
300.	-5.	37.97	-0.163	-1.628
	0.	51.53	-0.127	-1.275
	5.	40.24	-0.014	-0.140
	10.	30.57	0.006	0.061

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*************************************
*      GPS TEST    FAST TRACE      *
*  CHING-CHIU IONOSPHERIC MODEL    *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 03/21/87 1800 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	23.79	-0.036	-0.364
	0.	25.11	-0.014	-0.139
	5.	13.04	0.021	0.209
	10.	4.90	0.011	0.106
60.	-5.	1.51	-0.016	-0.158
	0.	2.79	-0.011	-0.114
	5.	2.08	0.000	0.004
	10.	1.62	0.001	0.013
120.	-5.	44.14	0.006	0.060
	0.	21.44	0.004	0.038
	5.	9.94	0.008	0.084
	10.	5.21	0.005	0.052
180.	-5.	198.04	0.022	0.216
	0.	108.88	0.052	0.520
	5.	50.11	0.051	0.514
	10.	22.70	0.030	0.299
240.	-5.	109.11	0.016	0.164
	0.	52.50	0.027	0.273
	5.	23.45	0.028	0.281
	10.	11.74	0.017	0.166
300.	-5.	14.91	-0.036	-0.364
	0.	13.34	-0.009	-0.093
	5.	8.08	0.009	0.094
	10.	5.27	0.008	0.080

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***************************************
*      GPS TEST     FAST TRACE        *
*   CHING-CHIU IONOSPHERIC MODEL      *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 06/21/87 0000 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	15.66	-0.013	-0.133
	0.	14.87	-0.001	-0.014
	5.	7.93	0.013	0.125
	10.	2.54	0.007	0.073
60.	-5.	1.18	-0.006	-0.064
	0.	1.38	-0.002	-0.023
	5.	0.84	0.002	0.015
	10.	0.58	0.001	0.013
120.	-5.	18.92	-0.002	-0.023
	0.	11.97	0.002	0.017
	5.	6.76	0.005	0.047
	10.	3.91	0.003	0.034
180.	-5.	64.39	-0.004	-0.038
	0.	44.21	0.010	0.102
	5.	25.97	0.016	0.157
	10.	14.44	0.012	0.120
240.	-5.	56.44	0.015	0.147
	0.	29.39	0.014	0.143
	5.	14.33	0.012	0.120
	10.	7.25	0.007	0.071
300.	-5.	1.21	-0.006	-0.064
	0.	1.40	-0.002	-0.023
	5.	0.87	0.001	0.015
	10.	0.61	0.001	0.012

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*    GPS TEST    FAST TRACE          *
*  CHING-CHIU IONOSPHERIC MODEL      *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 06/21/87 0600 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	40.22	-0.083	-0.826
	0.	43.40	-0.046	-0.464
	5.	29.46	0.017	0.170
	10.	16.31	0.019	0.195
60.	-5.	27.26	-0.079	-0.787
	0.	27.71	-0.040	-0.400
	5.	18.63	0.008	0.082
	10.	12.97	0.011	0.111
120.	-5.	38.97	-0.067	-0.674
	0.	32.37	-0.037	-0.366
	5.	20.74	0.009	0.089
	10.	14.04	0.011	0.111
180.	-5.	42.07	-0.064	-0.643
	0.	36.19	-0.039	-0.388
	5.	23.52	0.007	0.071
	10.	15.55	0.010	0.103
240.	-5.	19.47	-0.060	-0.601
	0.	21.56	-0.046	-0.461
	5.	15.56	-0.001	-0.008
	10.	11.28	0.005	0.049
300.	-5.	9.43	-0.066	-0.661
	0.	16.12	-0.048	-0.481
	5.	12.65	-0.002	-0.017
	10.	9.74	0.004	0.044

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***************************************
*      GPS TEST    FAST TRACE         *
*   CHING-CHIU IONOSPHERIC MODEL      *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 06/21/87 1200 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	74.36	-0.205	-2.053
	0.	91.88	-0.167	-1.668
	5.	68.92	-0.006	-0.061
	10.	44.68	0.019	0.188
60.	-5.	51.38	-0.197	-1.968
	0.	67.04	-0.160	-1.597
	5.	52.43	-0.022	-0.219
	10.	39.71	0.005	0.051
120.	-5.	111.02	-0.170	-1.702
	0.	93.32	-0.138	-1.380
	5.	63.91	-0.009	-0.087
	10.	45.29	0.012	0.123
180.	-5.	207.17	-0.169	-1.688
	0.	150.88	-0.106	-1.064
	5.	91.35	0.019	0.195
	10.	57.80	0.029	0.287
240.	-5.	102.63	-0.185	-1.855
	0.	93.90	-0.142	-1.424
	5.	65.42	-0.009	-0.086
	10.	46.29	0.013	0.130
300.	-5.	51.38	-0.197	-1.968
	0.	67.06	-0.160	-1.597
	5.	52.45	-0.022	-0.219
	10.	39.73	0.005	0.051

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*      GPS TEST    FAST TRACE          *
*   CHING-CHIU IONOSPHERIC MODEL       *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 06/21/87 1800 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	37.94	-0.083	-0.834
	0.	41.36	-0.045	-0.455
	5.	25.95	0.020	0.199
	10.	14.03	0.016	0.164
60.	-5.	9.47	-0.066	-0.660
	0.	16.13	-0.048	-0.481
	5.	12.66	-0.002	-0.017
	10.	9.75	0.004	0.044
120.	-5.	69.30	-0.035	-0.350
	0.	42.75	-0.028	-0.283
	5.	23.86	0.008	0.084
	10.	14.72	0.009	0.090
180.	-5.	200.98	-0.037	-0.367
	0.	126.97	0.009	0.086
	5.	66.62	0.046	0.463
	10.	34.56	0.033	0.333
240.	-5.	102.07	-0.040	-0.399
	0.	61.14	-0.014	-0.144
	5.	32.83	0.022	0.216
	10.	19.30	0.017	0.174
300.	-5.	27.26	-0.079	-0.787
	0.	27.73	-0.040	-0.401
	5.	18.65	0.008	0.082
	10.	13.01	0.011	0.110

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***************************************
*      GPS TEST     FAST TRACE        *
*   CHING-CHIU IONOSPHERIC MODEL      *
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SATELLITE: 40. 270.   100. KM ALT
DATE-TIME: 09/21/87   0000 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	22.31	-0.015	-0.151
	0.	20.74	0.002	0.016
	5.	9.76	0.019	0.187
	10.	2.49	0.008	0.084
60.	-5.	0.58	-0.004	-0.036
	0.	0.72	-0.001	-0.013
	5.	0.43	0.001	0.009
	10.	0.30	0.001	0.007
120.	-5.	9.52	0.000	-0.004
	0.	5.43	0.001	0.013
	5.	2.82	0.003	0.026
	10.	1.55	0.002	0.017
180.	-5.	34.46	0.002	0.022
	0.	20.95	0.008	0.081
	5.	11.03	0.009	0.090
	10.	5.64	0.006	0.060
240.	-5.	25.10	0.009	0.093
	0.	11.74	0.007	0.070
	5.	5.28	0.005	0.055
	10.	2.55	0.003	0.031
300.	-5.	0.59	-0.004	-0.037
	0.	0.73	-0.001	-0.013
	5.	0.45	0.001	0.009
	10.	0.31	0.001	0.007

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*       GPS TEST    FAST TRACE       *
*   CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 09/21/87 0600 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	25.15	-0.032	-0.318
	0.	26.07	-0.013	-0.133
	5.	15.97	0.018	0.181
	10.	6.36	0.014	0.138
60.	-5.	14.74	-0.036	-0.357
	0.	13.13	-0.009	-0.086
	5.	7.92	0.010	0.096
	10.	5.12	0.008	0.080
120.	-5.	29.46	-0.026	-0.262
	0.	19.48	-0.003	-0.033
	5.	10.78	0.012	0.123
	10.	6.55	0.009	0.094
180.	-5.	31.36	-0.017	-0.166
	0.	20.83	-0.003	-0.027
	5.	11.53	0.010	0.097
	10.	6.63	0.007	0.075
240.	-5.	11.63	-0.012	-0.121
	0.	8.23	-0.008	-0.078
	5.	4.85	0.003	0.028
	10.	3.06	0.003	0.028
300.	-5.	1.47	-0.015	-0.153
	0.	2.74	-0.011	-0.109
	5.	2.03	0.001	0.006
	10.	1.57	0.002	0.015

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*************************************
*      GPS TEST    FAST TRACE       *
*  CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 09/21/87 1200 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	51.00	-0.166	-1.663
	0.	66.69	-0.132	-1.325
	5.	49.58	-0.002	-0.020
	10.	32.43	0.014	0.140
60.	-5.	37.81	-0.162	-1.623
	0.	51.32	-0.127	-1.270
	5.	40.05	-0.014	-0.139
	10.	30.41	0.006	0.062
120.	-5.	117.62	-0.129	-1.287
	0.	87.07	-0.097	-0.971
	5.	55.89	0.005	0.051
	10.	38.23	0.017	0.167
180.	-5.	227.03	-0.139	-1.387
	0.	154.62	-0.060	-0.604
	5.	87.98	0.041	0.405
	10.	52.84	0.038	0.375
240.	-5.	100.02	-0.153	-1.529
	0.	84.89	-0.106	-1.060
	5.	56.61	0.004	0.037
	10.	38.98	0.017	0.170
300.	-5.	37.79	-0.162	-1.623
	0.	51.32	-0.127	-1.270
	5.	40.07	-0.014	-0.139
	10.	30.44	0.006	0.061

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*      GPS TEST    FAST TRACE        *
*   CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 09/21/87 1800 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	22.92	-0.033	-0.328
	0.	24.04	-0.012	-0.117
	5.	12.25	0.021	0.207
	10.	4.34	0.010	0.101
60.	-5.	1.49	-0.015	-0.152
	0.	2.74	-0.011	-0.109
	5.	2.04	0.001	0.006
	10.	1.57	0.002	0.015
120.	-5.	41.05	0.005	0.046
	0.	20.18	0.003	0.032
	5.	9.43	0.008	0.082
	10.	4.97	0.005	0.052
180.	-5.	180.51	0.019	0.193
	0.	99.73	0.048	0.480
	5.	46.05	0.047	0.473
	10.	20.85	0.028	0.276
240.	-5.	101.66	0.012	0.123
	0.	49.53	0.025	0.250
	5.	22.30	0.027	0.269
	10.	11.23	0.016	0.160
300.	-5.	14.76	-0.036	-0.357
	0.	13.16	-0.009	-0.087
	5.	7.95	0.010	0.095
	10.	5.16	0.008	0.080

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*************************************
*      GPS TEST    FAST TRACE       *
*  CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 12/21/87 0000 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	32.75	-0.020	-0.204
	0.	28.94	0.008	0.079
	5.	11.55	0.028	0.276
	10.	2.41	0.009	0.094
60.	-5.	0.39	-0.003	-0.027
	0.	0.51	-0.001	-0.010
	5.	0.31	0.001	0.006
	10.	0.21	0.001	0.005
120.	-5.	5.02	0.000	-0.002
	0.	2.62	0.001	0.006
	5.	1.26	0.002	0.015
	10.	0.67	0.001	0.010
180.	-5.	21.26	0.005	0.046
	0.	11.14	0.007	0.065
	5.	5.14	0.006	0.057
	10.	2.39	0.003	0.033
240.	-5.	11.41	0.005	0.051
	0.	4.79	0.003	0.032
	5.	2.00	0.003	0.026
	10.	0.94	0.001	0.015
300.	-5.	0.39	-0.003	-0.027
	0.	0.51	-0.001	-0.010
	5.	0.31	0.001	0.006
	10.	0.21	0.001	0.005

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*      GPS TEST     FAST TRACE       *
*   CHING-CHIU IONOSPHERIC MODEL     *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 12/21/87 0600 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	22.50	-0.018	-0.181
	0.	22.36	-0.004	-0.043
	5.	12.18	0.019	0.188
	10.	3.61	0.011	0.108
60.	-5.	2.19	-0.007	-0.075
	0.	2.03	-0.003	-0.025
	5.	1.20	0.002	0.020
	10.	0.80	0.002	0.017
120.	-5.	15.40	0.006	0.062
	0.	6.71	0.003	0.031
	5.	3.11	0.004	0.043
	10.	1.71	0.003	0.028
180.	-5.	21.38	-0.002	-0.017
	0.	12.03	0.004	0.043
	5.	5.91	0.007	0.068
	10.	3.07	0.004	0.043
240.	-5.	7.06	-0.005	-0.048
	0.	4.50	-0.002	-0.016
	5.	2.44	0.003	0.026
	10.	1.45	0.002	0.020
300.	-5.	0.78	-0.007	-0.071
	0.	1.31	-0.004	-0.038
	5.	0.88	0.001	0.011
	10.	0.63	0.001	0.012

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************************************
*      GPS TEST    FAST TRACE      *
*  CHING-CHIU IONOSPHERIC MODEL    *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 12/21/87 1200 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	28.35	-0.112	-1.118
	0.	39.79	-0.084	-0.841
	5.	28.55	0.005	0.050
	10.	18.34	0.011	0.108
60.	-5.	21.22	-0.110	-1.105
	0.	30.71	-0.080	-0.801
	5.	23.66	-0.004	-0.035
	10.	17.98	0.007	0.071
120.	-5.	127.54	-0.059	-0.590
	0.	76.65	-0.037	-0.370
	5.	43.52	0.022	0.217
	10.	27.68	0.021	0.206
180.	-5.	277.62	-0.073	-0.728
	0.	165.58	0.020	0.199
	5.	83.41	0.073	0.725
	10.	45.10	0.049	0.486
240.	-5.	94.13	-0.099	-0.991
	0.	69.76	-0.054	-0.537
	5.	42.80	0.018	0.175
	10.	27.90	0.020	0.199
300.	-5.	21.16	-0.111	-1.106
	0.	30.69	-0.080	-0.801
	5.	23.67	-0.004	-0.036
	10.	18.01	0.007	0.070

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***************************************
*      GPS TEST     FAST TRACE        *
*   CHING-CHIU IONOSPHERIC MODEL      *
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SATELLITE: 40. 270. 100. KM ALT
DATE-TIME: 12/21/87 1800 HOURS
FREQUENCY: 1.0 GIGAHERTZ
SUNSPOT NUMBER: 200.

AZIM DEG	ELEV DEG	DELAY NSECS	ANGLE MRADS	DISTANCE METERS
0.	-5.	20.33	-0.019	-0.194
	0.	20.29	-0.002	-0.016
	5.	8.28	0.020	0.204
	10.	1.90	0.007	0.067
60.	-5.	0.78	-0.007	-0.071
	0.	1.31	-0.004	-0.038
	5.	0.88	0.001	0.011
	10.	0.64	0.001	0.012
120.	-5.	20.43	0.005	0.046
	0.	9.42	0.004	0.036
	5.	4.23	0.005	0.048
	10.	2.19	0.003	0.030
180.	-5.	132.39	0.036	0.360
	0.	64.91	0.048	0.476
	5.	26.64	0.035	0.345
	10.	10.90	0.018	0.176
240.	-5.	83.05	0.054	0.537
	0.	31.13	0.032	0.324
	5.	11.34	0.017	0.173
	10.	4.77	0.008	0.080
300.	-5.	2.22	-0.007	-0.075
	0.	2.06	-0.003	-0.026
	5.	1.23	0.002	0.020
	10.	0.84	0.002	0.016

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 06/21/87 0000 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	10.6	14.2	
0.	7.4	10.0	
5.	4.4	5.9	
10.	3.1	4.2	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	4.4	5.8	
0.	4.9	6.5	
5.	4.0	5.3	
10.	3.0	4.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	4.9	6.6	
0.	4.9	6.6	
5.	3.9	5.3	
10.	3.0	4.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	9.9	13.3	
0.	7.2	9.6	
5.	4.8	6.4	
10.	3.3	4.4	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	7.4	10.0	
0.	5.7	7.6	
5.	4.2	5.6	
10.	3.1	4.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	4.4	5.8	
0.	4.9	6.5	
5.	4.0	5.3	
10.	3.0	4.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 06/21/87 0600 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	22.3	29.8	
0.	21.5	28.8	
5.	13.8	18.5	
10.	9.7	13.0	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	15.8	21.2	
0.	17.7	23.7	
5.	13.4	18.0	
10.	10.0	13.3	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	16.2	21.7	
0.	17.5	23.4	
5.	13.3	17.8	
10.	9.8	13.2	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	15.1	20.3	
0.	16.3	21.9	
5.	12.6	16.8	
10.	9.4	12.6	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	9.0	12.1	
0.	13.6	18.2	
5.	11.4	15.3	
10.	8.9	11.9	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	10.3	13.8	
0.	14.2	19.0	
5.	11.7	15.6	
10.	9.0	12.1	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 06/21/87 1200 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	29.2	39.1	
0.	31.7	42.5	
5.	20.8	27.9	
10.	15.0	20.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	20.7	27.7	
0.	26.2	35.1	
5.	20.1	26.9	
10.	15.1	20.2	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	25.9	34.7	
0.	28.2	37.8	
5.	20.9	28.1	
10.	15.5	20.8	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	39.2	52.6	
0.	32.8	43.9	
5.	22.3	29.9	
10.	16.0	21.5	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	26.3	35.2	
0.	28.6	38.3	
5.	21.1	28.2	
10.	15.6	20.8	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	20.7	27.7	
0.	26.2	35.1	
5.	20.1	26.9	
10.	15.1	20.2	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 06/21/87 1800 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	20.6	27.6	
0.	19.1	25.5	
5.	13.0	17.4	
10.	9.6	12.9	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	10.3	13.8	
0.	14.2	19.0	
5.	11.7	15.6	
10.	9.0	12.1	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	12.2	16.4	
0.	14.4	19.3	
5.	11.6	15.6	
10.	8.9	12.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	33.2	44.5	
0.	22.6	30.3	
5.	14.3	19.1	
10.	9.9	13.3	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	21.5	28.9	
0.	19.0	25.4	
5.	13.7	18.3	
10.	10.0	13.4	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	15.8	21.2	
0.	17.7	23.7	
5.	13.4	18.0	
10.	10.0	13.3	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 09/21/87 0000 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	11.6	15.6	
0.	6.9	9.2	
5.	3.3	4.5	
10.	2.3	3.1	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	3.1	4.1	
0.	3.5	4.7	
5.	2.9	3.9	
10.	2.2	3.0	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	3.6	4.8	
0.	3.6	4.8	
5.	2.9	3.9	
10.	2.2	3.0	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	6.7	9.0	
0.	5.0	6.6	
5.	3.4	4.5	
10.	2.4	3.2	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	4.8	6.4	
0.	4.0	5.3	
5.	3.0	4.1	
10.	2.3	3.0	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	3.1	4.2	
0.	3.5	4.7	
5.	2.9	3.9	
10.	2.2	3.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 09/21/87 0600 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	15.4	20.7	
0.	13.6	18.3	
5.	8.0	10.7	
10.	5.4	7.3	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	12.4	16.6	
0.	12.8	17.2	
5.	9.6	12.8	
10.	7.0	9.4	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	13.3	17.8	
0.	13.2	17.6	
5.	9.7	13.0	
10.	7.0	9.4	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	9.9	13.3	
0.	9.7	12.9	
5.	7.4	9.9	
10.	5.5	7.4	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	5.3	7.1	
0.	6.4	8.5	
5.	5.4	7.3	
10.	4.3	5.8	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	4.4	5.9	
0.	6.0	8.0	
5.	5.3	7.1	
10.	4.2	5.7	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 09/21/87 1200 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	24.0	32.2	
0.	27.5	36.8	
5.	18.9	25.4	
10.	13.9	18.6	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	18.8	25.2	
0.	24.0	32.2	
5.	18.6	24.9	
10.	14.0	18.8	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	24.8	33.3	
0.	26.5	35.6	
5.	19.7	26.4	
10.	14.6	19.5	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	37.3	50.0	
0.	31.0	41.6	
5.	21.1	28.3	
10.	15.1	20.3	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	24.7	33.1	
0.	26.7	35.8	
5.	19.8	26.5	
10.	14.6	19.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	18.8	25.2	
0.	24.0	32.2	
5.	18.6	24.9	
10.	14.0	18.8	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 09/21/87 1800 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	13.8	18.5	
0.	11.2	15.0	
5.	7.2	9.7	
10.	5.3	7.2	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	4.4	5.9	
0.	6.0	8.0	
5.	5.3	7.1	
10.	4.3	5.7	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	7.2	9.7	
0.	6.8	9.2	
5.	5.6	7.5	
10.	4.4	5.8	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	24.3	32.5	
0.	14.5	19.4	
5.	8.7	11.6	
10.	5.9	7.9	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	18.2	24.4	
0.	14.5	19.4	
5.	10.1	13.5	
10.	7.2	9.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	12.4	16.6	
0.	12.8	17.2	
5.	9.6	12.8	
10.	7.0	9.4	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 12/21/87 0000 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	14.6	19.6	
0.	7.6	10.1	
5.	3.0	4.0	
10.	1.9	2.6	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	2.5	3.4	
0.	2.9	3.9	
5.	2.4	3.3	
10.	1.9	2.5	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	3.1	4.1	
0.	3.1	4.2	
5.	2.5	3.4	
10.	1.9	2.6	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	5.9	7.8	
0.	4.2	5.7	
5.	2.9	3.9	
10.	2.0	2.7	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	3.8	5.1	
0.	3.3	4.4	
5.	2.6	3.4	
10.	1.9	2.6	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	2.5	3.4	
0.	2.9	3.9	
5.	2.4	3.3	
10.	1.9	2.5	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 12/21/87 0600 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	12.2	16.4	
0.	9.9	13.2	
5.	5.0	6.7	
10.	3.2	4.3	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	5.7	7.6	
0.	5.8	7.7	
5.	4.5	6.0	
10.	3.4	4.5	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	8.5	11.3	
0.	6.6	8.8	
5.	4.8	6.4	
10.	3.5	4.7	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	7.1	9.5	
0.	6.2	8.3	
5.	4.6	6.2	
10.	3.4	4.6	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	4.3	5.8	
0.	4.8	6.4	
5.	4.0	5.3	
10.	3.1	4.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	3.4	4.5	
0.	4.3	5.8	
5.	3.8	5.1	
10.	3.0	4.0	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 12/21/87 1200 HRS
SUNSPOT NUMBER IS 0.

HORZ ANG	TEC	NSEC	AZIM = 0.
-5.	17.8	23.9	
0.	21.6	29.0	
5.	15.7	21.0	
10.	11.8	15.7	

HORZ ANG	TEC	NSEC	AZIM = 60.
-5.	15.3	20.5	
0.	19.9	26.6	
5.	15.8	21.1	
10.	12.0	16.1	

HORZ ANG	TEC	NSEC	AZIM = 120.
-5.	23.8	31.8	
0.	23.4	31.3	
5.	17.3	23.1	
10.	12.8	17.1	

HORZ ANG	TEC	NSEC	AZIM = 180.
-5.	40.5	54.2	
0.	29.3	39.3	
5.	19.1	25.6	
10.	13.5	18.1	

HORZ ANG	TEC	NSEC	AZIM = 240.
-5.	22.8	30.5	
0.	23.4	31.4	
5.	17.3	23.2	
10.	12.8	17.1	

HORZ ANG	TEC	NSEC	AZIM = 300.
-5.	15.3	20.5	
0.	19.9	26.6	
5.	15.8	21.1	
10.	12.0	16.1	

SATELLITE POSITION

LAT 40.00 LON 270.00 ALT 100. KM
DATE AND TIME 12/21/87 1800 HRS
SUNSPOT NUMBER IS 0.

AZIM = 0.

HORZ ANG	TEC	NSEC
-5.	10.5	14.1
0.	7.4	9.9
5.	4.3	5.7
10.	3.1	4.2

AZIM = 60.

HORZ ANG	TEC	NSEC
-5.	3.4	4.5
0.	4.3	5.8
5.	3.8	5.1
10.	3.0	4.0

AZIM = 120.

HORZ ANG	TEC	NSEC
-5.	5.5	7.4
0.	5.1	6.8
5.	4.1	5.4
10.	3.1	4.2

AZIM = 180.

HORZ ANG	TEC	NSEC
-5.	20.3	27.1
0.	10.2	13.7
5.	5.6	7.5
10.	3.7	4.9

AZIM = 240.

HORZ ANG	TEC	NSEC
-5.	13.6	18.2
0.	7.8	10.4
5.	5.1	6.8
10.	3.6	4.8

AZIM = 300.

HORZ ANG	TEC	NSEC
-5.	5.7	7.6
0.	5.8	7.7
5.	4.5	6.1
10.	3.4	4.5